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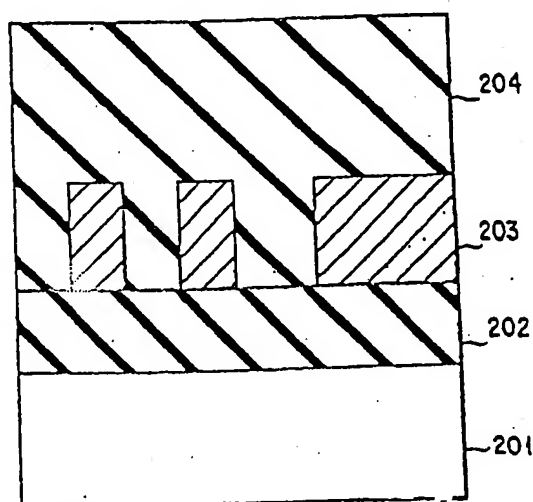
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SEMICONDUCTOR DEVICE AND PROCESS FOR ITS MANUFACTURE

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The present invention concerns a semiconductor device comprising a substrate 201 and at least one intermediate-layer insulation film 204 or one passivation-insulation film, each of which is formed on the substrate 201 and contains silicon, oxygen, carbon, and hydrogen, where the carbon content is greater than the silicon content. The insulation film has a dielectric constant of 1.8 to 3.2 and is viscous at room temperature, wherein it has a viscosity from 100-300,000 cps at room temperature.



The present invention concerns a semiconductor device and a process for its manufacture; in particular, the present invention concerns an insulation film such as an intermediate-layer insulation film or a protective insulation film (a passivation film) of a semiconductor device.

For some time, large-scale integrated circuits (LSI), comprising circuits that are composed of a large number of transistors and resistors, have been formed on individual chips, which are extensively used in critical areas of computers or telecommunications systems. It can therefore be said that the performance of such systems is strongly influenced by the performance of the individual LSI unit.

The performance of the LSI unit can be increased by raising the degree of integration, i.e., through miniaturizing each element in the LSI unit individually. However, there are various problems in the manufacturing process for miniaturization.

If, e.g., an aluminum-alloy conductor is taken as an example, there has been a clear advance in the miniaturization of the width of the conductor and the intermediate space between the conductors. In regard to the thickness of the conductor, however, only a moderate advance has been achieved in making the conductor thinner. If a silicon dioxide film is formed in order to cover an aluminum-alloy conductor, the grooves between the conductors may therefore not be filled completely with the silicon dioxide film, in which case holes are left in the insulation film. These holes can cause a residue of  $H_2O$  in the insulation film, which in turn causes corrosion of the aluminum-alloy conductor, since this  $H_2O$  residue gets from the insulation film to the aluminum-alloy conductor.

Conventional silicon-oxide films likewise have the problem that, because of the inherent tension of the film or a large thermal tension in the film, the phenomenon of thermal migration is induced, whereby a detachment of the aluminum-alloy wire is caused.

A process for coating spin-on-glass (SOG) and the thermal hardening thereof is known as a process for hiding a fine groove between the conductors with an insulation material while avoiding the formation of holes.

In this process, the SOG must have a low viscosity, in order for a fine groove to be filled sufficiently with the SOG. However, the use of an SOG with a low viscosity has the problem that large shrinkage in volume occurs when it is then hardened thermally, whereby cracks are generated in the SOG, and that it is difficult to remove water from it adequately. The problem of corrosion of an aluminum-alloy conductor in the subsequent steps remains unsolved in this process.

On the other hand, in order to obtain a semiconductor device of the next generation with a higher operating speed, the intermediate-layer insulation film to insulate the aluminum-alloy conductors from each other must have a lower dielectric constant than the intermediate-layer

insulation film used at present. In order to meet this requirement, the use of a silicon dioxide film to which fluorine has been added (fluorine-containing silicon dioxide film) is promising.

However, when the fluorine concentration is increased in order to lower the dielectric constant, the film becomes more hygroscopic, in which case the problem arises that water can be released from the fluorine-containing silicon dioxide film, whereby its properties as an intermediate-layer insulation film are worsened or corrosion of the aluminum-alloy conductors is made possible.

When a silicon dioxide film is used as an intermediate-layer insulation film, it is difficult, as explained above, to fill a fine groove placed laterally between the conductors in a satisfactory manner without causing holes to be formed, since the shape of the silicon dioxide film contained in it has defects. Water therefore remains in the intermediate-layer insulation film, whereby corrosion of the conductors is caused.

In order to solve these problems, a process for filling a fine groove between the conductors with a low-viscosity SOG and with subsequent thermal hardening has been recommended, as mentioned above. However, the use of an SOG with a [low] viscosity has the problem that during thermal hardening a large shrinkage in volume occurs, in which case the creation of cracks is induced in the SOG, and in addition, it is difficult to remove water from it adequately. Therefore, the problem of corrosion in a conductor during the next step is also not solved by this process.

On the other hand, the use of a fluorine-containing silicon dioxide film to produce a semiconductor device of the next generation, with a high operating speed is seen as promising. However, when the fluorine concentration is raised in order to lower the dielectric constant of the film, the film becomes more hygroscopic, which causes the problem that water can be released from the fluorine-containing silicon dioxide film during the manufacturing process, whereby its properties as an intermediate-layer insulation film are worsened or corrosion of the aluminum-alloy conductors results.

Accordingly, one goal of the present invention is to provide a semiconductor device that is provided with an insulating film that can effectively fill a fine groove.

Another goal of the present invention is to specify a method of producing a semiconductor device provided with an insulation film that is effective in covering a fine groove.

Another goal of the present invention is to provide a process for producing a semiconductor device that is provided with an insulation film that is suitable for use at least as an intermediate-layer insulation film or passivation layer that is more ideal in regard to shape in the embedded state and has a lower dielectric constant and is less hygroscopic than conventional insulation films.

Another goal of the present invention is to provide a semiconductor device that is provided with an insulation film suitable for use as an intermediate-layer insulation film that is more ideal in regard to shape in the embedded state and has a lower dielectric constant and lower thermal tension than conventional films.

Another goal of the present invention is to provide a semiconductor device that is provided with an insulation film suitable for use as an intermediate-layer insulation film that is ideal in regard to shape in the embedded state (high degree of coverage) and gives hardly any adverse effect on the next step (e.g., a step for forming a contact hole or a step for forming a conductor) in comparison with conventional insulation films.

Another goal of the present invention is to provide a process for producing a semiconductor device that has the ideal characteristics mentioned above.

According to the invention, a semiconductor device is provided that includes: a substrate and at least one intermediate-layer insulation film or a passivation film, each formed on the substrate, containing silicon, oxygen, carbon, and hydrogen, whereby the carbon content is not less than the silicon content.

According to the invention, a semiconductor device is also made available that includes: a substrate and at least one intermediate-layer insulation film or a passivation film, wherein each is formed on the substrate and contains silicon, oxygen, carbon, and hydrogen, and is viscous at room temperature, wherein its viscosity is 100 cps to 300,000 cps at room temperature.

According to the invention, a semiconductor device is also made available that includes a semiconductor substrate that carries an element; a first insulation film formed on the semiconductor substrate; a number of conductors, wherein at least one of the conductors is connected electrically to the element through a contact hole; a second insulation film, which is formed on the conductors and the first insulation film where conductors have not been formed and which contains silicon, oxygen, carbon, and hydrogen, wherein the carbon content is not less than the silicon content; and a third insulation film, which is formed on the second insulation film and is of a material that differs from the material from which the second insulation film is made.

According to the invention, a semiconductor device is also made available that includes a semiconductor substrate; a first conducting film, which is formed on the semiconductor substrate; and a second conducting film, which is formed on the insulation film in such a way that it is in electrical contact with the first conducting film through the contact hole, wherein a region of the insulation film in the neighborhood of a boundary surface with the second conducting film, except for a region at the contact hole, is constructed in such a way that it has a viscosity of 10,000 cp or higher and wherein the rest of the insulation film, except for the region

in the neighborhood of the boundary surface between it and the second conducting film, is constructed in such way that it has a viscosity of less than 10,000 cp.

According to the invention, a process is also provided for producing a semiconductor device, including these steps: forming a first insulation film on a semiconductor substrate that carries an element; forming a contact hole in the first insulation film; forming a number of conductors on the first insulation film, wherein at least one of the many conductors is in electrical contact with the element through the contact hole; forming a second insulation film on the first insulation film, where the conductors have not been formed, in such a way that the space between the conductors is covered, and wherein the second insulation film contains silicon, oxygen, carbon, and hydrogen, wherein the carbon content is not less than the silicon content; and forming a third insulation film on the conductors and on the second insulation film, wherein the third insulation film is made of a material that differs from the material of which the second insulation film is made.

According to the invention, a process is also provided for producing a semiconductor device, including these steps: forming a first conducting film on a substrate; forming an insulation film with a viscosity of less than 10,000 cp, by means of which the first conducting film is covered; performing a viscosity-increasing treatment, by means of which the viscosity of a surface layer of the insulation film is increased to not less than 10,000 cp; and forming a second conducting film on the insulation film in such a way that it is in electrical contact with the first conducting film.

According to the invention, a process is also provided for producing a semiconductor device, including these steps: forming a first conducting film on a substrate; forming an insulating film with a viscosity of less than 10,000 cp, wherein the first conducting film is covered; forming a second insulation film with a viscosity of not less than 10,000 cp on the first insulation film; and forming a section conducting film on the second insulation film in such a way that it is in electrical contact with the first conducting film;

Additional goals and advantages of the present invention will be explained on the basis of the following description and will partly become clear on the basis of the description or can be understood by implementing the present invention. These goals and advantages of the invention can be realized and obtained in particularly through the characteristics given in the attached patent claims and combinations thereof.

The attached drawings, which constitute a part of the description and are contained therein, explain preferred embodiment examples and serve, together with the general description given above and the detailed description given below, to clarify, in addition to these preferred embodiment examples, the principles of the present invention.

Figure 1 is a schematic diagram that shows the structure of a semiconductor device that is used according to a first example of the present invention;

Figure 2 is a schematic diagram that shows that structure of a nitrogen-gas supply system;

Figures 3A and 3B each show sections through a semiconductor device that explain a second example according to the production process;

Figure 4 is a schematic diagram that shows the structure of a semiconductor device that is used in a third example of the present invention;

Figures 5A through 5C each show a section through a semiconductor device, wherein the production process according to a third example of the present invention is explained;

Figure 6 is a diagram that explains the dependency of the film thickness of an insulation film on the lower layer;

Figures 7A through 7C each show a section through a semiconductor device, wherein the production step corresponding to a fourth example of the present invention is explained;

Figure 8 is a cross section through a semiconductor device corresponding to a fifth example of the present invention;

Figure 9 is a schematic diagram that show the structure of a semiconductor device that is used according to a fifth example of the present invention;

Figures 10A through 10C each show a cross section through a semiconductor device, wherein the production step corresponding to a fifth example of the present invention is explained;

Figure 11A shows a cross section through a semiconductor device, wherein a process to prevent deformation of a soft passivation layer according to the present invention is explained; and

Figure 11B shows a schematic plan view, wherein a process for preventing deformation of a soft passivation layer according to the present invention is explained.

A semiconductor device corresponding to a first embodiment example of the present invention is characterized by the use of an insulation film with low viscosity as an intermediate-layer insulation film and/or a protection-insulation film (passivation film).

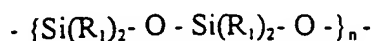
This insulation film includes silicon, oxygen, carbon, and hydrogen, whereby the carbon content is not less than the silicon content. For example, the atomic ratio of carbon to silicon in this insulation film should preferably be from 1.0 to 3.0, more preferably, from 1.0 to 2.0. If the carbon content is higher than the silicon content, the insulation film is more viscous.

The insulation film according to the invention has a viscosity between 100 and 300,000 cps, more preferably from 1000 to 10,000 cps, at room temperature. In this case, "room temperature" means a temperature range of about 15-30°C.

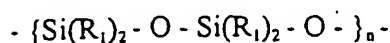
If the viscosity of the insulation film is less than 100 cps, the insulation film cannot be used for a multi-layer intermediate circuit. On the other hand, if the viscosity of the insulation film exceeds 300,000 cps, holes may be formed in the insulation film when it is embedded in a fine groove.

Insulation films according to the invention should preferably have a dielectric constant from 1.8 to 3.2, more preferably 1.0 to 2.5.

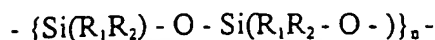
Specific examples of the insulation film according to the present invention as those that have a backbone chain selected from the group consisting of the following formulas 1-5:



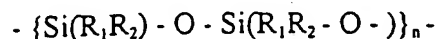
where  $\text{R}_1$  is  $\text{C}_n\text{H}_{2n+1}$  (where  $n$  denotes a positive integer);



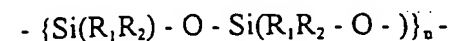
where  $\text{R}_1$  is  $-\text{O}-\text{C}_n\text{H}_{2n+1}$  (where  $n$  denotes a positive integer);



where  $\text{R}_1$  is  $\text{C}_n\text{H}_{2n+1}$  (where  $n$  denotes a positive integer) and  $\text{R}_2$  is  $\text{C}_m\text{H}_{2m+1}$  (where  $m$  denotes a positive integer), where  $n$  differs from  $m$ ;



where  $\text{R}_1$  is  $-\text{O}-\text{C}_n\text{H}_{2n+1}$  (where  $n$  denotes a positive integer) and  $\text{R}_2$  is  $-\text{O}-\text{C}_m\text{H}_{2m+1}$  (where  $m$  denotes a positive integer), where  $n$  differs from  $m$ ; and



where  $\text{R}_1$  is  $-\text{O}-\text{C}_n\text{H}_{2n+1}$  or  $\text{C}_n\text{H}_{2n+1}$  (where  $n$  is a positive integer);  $\text{R}_2$  is  $-\text{O}-\text{C}_m\text{H}_{2m+1}$  or  $\text{C}_m\text{H}_{2m+1}$  (where  $m$  is a positive integer), where  $n$  differs from  $m$  and where at least one of  $\text{R}_1$  and  $\text{R}_2$  is connected by  $-\text{O}-$  to  $\text{R}_1$  or  $\text{R}_2$  belonging to the other backbone chain.

If the insulation film corresponding to this example is formed over a large surface, a circuit column consisting of a metallic material or insulation material, which differs from the material of which the insulation film is made and is resistant to flow and deformation of the insulation film, can be formed in the insulation film. By providing such a circuit column, deformation of the insulation film can be suppressed.

It is likewise possible to suppress deformation of the insulation film, even if tension is applied to the insulation film, by making the viscosity of the surface region of the insulation film according to this embodiment example higher than that of the inner region of the insulation film.



The insulation film according to the first embodiment example of the present invention has an excellent property in that it is inert and cannot release water at a temperature below 650°C. The insulation film corresponding to the first embodiment example can be formed by a CVD process. This CVD process should preferably be implemented in such a way that the temperature of the substrate is set to a temperature that is higher than the melting point and lower than the boiling point of a gaseous starting material or an intermediate product that can be formed by a reaction of the starting material in a vapor phase.

It has been established that when the carbon content in the insulation film corresponding to this embodiment example, which contains silicon, oxygen, carbon, and hydrogen, is higher than the silicon content, the insulation film becomes viscous at room temperature (viscosity from 100-300,000 cps), so that the shape of the insulation film can be improved when it is embedded in a fine groove.

For example, it has been established that the insulation film corresponding to this example embodiment can fill a groove with a high length ratio of more than 1, without the usual holes being able to be concealed in it. The insulation film with such a viscosity, containing silicon, oxygen, carbon, and hydrogen, likewise has a low dielectric constant and is less hygroscopic. For example, the dielectric constant of the insulation film can be set in the range 1.8-3.2. It has likewise been established that the insulation film corresponding to this embodiment example is thermally stable and cannot release water a temperature below 650°C.

In the semiconductor device of this embodiment example, in which the above-mentioned insulation film is used as an intermediate-layer insulation film or passivation film, it is possible to create an intermediate-layer insulation film or a passivation film that is excellent in regard to the embedded shape and has a low dielectric constant and is less hygroscopic. Since the insulation film corresponding to this embodiment example is very viscous, thermal tension can be minimized.

The semiconductor device corresponding to the second embodiment example of the present invention is characterized by the fact that it includes: a semiconductor substrate that carries an element; a first insulation film, formed on the semiconductor substrate; a number of conductors, wherein at least one of the conductors is connected electrically to the element; a second insulation film, formed on the conductors and on the first insulation film where conductors have not been formed and containing silicon, oxygen, carbon, and hydrogen, wherein the carbon content is higher than the silicon content; and a third insulation film formed on the second insulation film and made from a material that differs from the material from which the second insulation is made.

The semiconductor device corresponding to the second embodiment example of the present invention can be produced by a process that includes the steps: formation of a first

insulation film on a semiconductor substrate that carries an element; forming a contact hole in the first insulation film; forming a number of conductors in the first insulation film, wherein at least one of the many conductors is connected electrically to the element through the contact hole; forming a second insulation film on the first insulation film where conductors have not been formed in such a way that the space between the conductors is filled, where the second insulation film contains silicon, oxygen, carbon, and hydrogen, wherein the carbon content is higher than the silicon content; and forming a third insulation film on the conductors and on the second insulation film, wherein the third insulation film is made from a material that differs from the material from which the second insulation film is made.

The second insulation film corresponding to this embodiment example can be formed by means of a CVD process, wherein an organic silane and oxygen in an excited state are used as starting materials and a substrate temperature of  $-70^{\circ}\text{C}$  to  $50^{\circ}\text{C}$  is set.

The expression "a material that differs from the material that forms the second insulation film" means cases in which the elements that make up the material are the same, but differ in the composition, as well as cases in which the elements that make up the material differ from one another.

The film thickness of the third insulation film, which is formed onto the second insulation film, should preferably be thinner than the film thickness of the third [sic; second] insulation film that is formed on the upper surface of the first insulation film that is provided between the conductors.

The first and third insulation films should preferably be silicon dioxide films.

Since the insulation film corresponding to the first embodiment example of the present invention is used as a second insulation film (an intermediate-layer insulation film) in the semiconductor device according to the present invention, it is possible to obtain a semiconductor device with a second insulation film (an intermediate-layer insulation film) that is excellent in regard to the embedded form and has a low dielectric constant and is less hygroscopic, as well as a process for producing such a semiconductor device.

If the above-mentioned second insulation film (an intermediate-layer insulation film) is formed on a conductor such as an aluminum conductor, the conductor can be prevented from being subject to a large thermal tension, wherein the generation of tension migration can be effectively prevented.

Since the third insulation film, which is made from a different material than the one used for the second insulation film, is formed on the second insulation film, any incompatibility effect resulting from the second insulation film can be prevented. If, e.g., the same material as in the conventional intermediate-insulation film is used as the third insulation film, an upper conductor

(4) The step of increasing the viscosity of the surface layer of the insulation film to not less than 10,000 cp is performed by irradiating the insulation film with an infrared-radiation source with a wavelength of 2.6-3.5  $\mu\text{m}$ .

(5) The step of increasing the viscosity of a surface layer of an insulation film to not less than 10,000 cp is performed by irradiating the insulation film with an ultraviolet-radiation source with a wavelength from 142-380 nm.

(6) The step of increasing the viscosity of a surface layer of the insulation film to not less than 10,000 cp is performed by subjecting the insulation film to microwave radiation in an atmosphere of a gas that is made up of at least one oxygen-containing molecule, an atmosphere of an inert gas, or an atmosphere at reduced pressure.

(7) The step of increasing the viscosity of a surface layer of the insulation film to not less than 10,000 cp is performed by heating the substrate that carries the insulation film at a heating rate of 10  $^{\circ}\text{C}/\text{s}$  and by maintaining the heating temperature at 450  $^{\circ}\text{C}$  or less.

(8) The step of increasing the viscosity of a surface layer of the insulation film to not less than 10,000 cp is performed by heating the substrate that carries the insulation at a heating rate of 10  $^{\circ}\text{C}/\text{s}$ , whereby the surface layer of the insulation film is heated to a temperature in the range 450 $^{\circ}\text{C}$ -700 $^{\circ}\text{C}$ .

(9) A system is used that is capable of performing continuously, without leaving the vacuum state, the step of forming an insulation film with a viscosity of less than 10,000 cp to cover the first conducting film and the step of increasing the viscosity of a surface layer of the insulation film to not less than 10,000 cp.

(10) The system of the above-mentioned embodiment 9 is constructed so that the above-mentioned step of continuous performance can be performed in the same vacuum container, without breaking the vacuum state.

(11) In the above-mentioned embodiment example 1, the insulation film used is one formed by a CVD process.

(12) In the above-mentioned embodiments 2-8, formation of the insulation film is achieved by a CVD process.

(13) In the above-mentioned embodiments 9-10, formation of the insulation film is achieved by using a CVD system.

(14) In the above-mentioned embodiment 1, a region of the insulation film is placed in the neighborhood of a boundary surface between it and a region of the second insulation film located at a side wall of the contact hole, constructed in such a way that the inequality  $d_{\text{max}} \leq 0.1 t_{\text{max}}$  is satisfied, where  $t_{\text{max}}$  denotes a maximum film thickness and  $d_{\text{max}}$  denotes a maximum distance from the boundary surface with the second conducting film to the region of the insulation film arranged in the neighborhood of the intermediate surface.

(15) In the above-mentioned embodiment 1, a region of the insulation film is arranged in the neighborhood of a boundary surface between it and a region of the second conducting film located at a side wall of the contact hole, constructed in such a way that the following inequality is satisfied:  $10 \text{ nm} \leq d_{\text{max}} \leq 100 \text{ nm}$ , where  $d_{\text{max}}$  denotes a maximum distance from the boundary surface between it and the second conducting film to the region of the insulation film arranged in the neighborhood of the boundary surface.

(16) In the above-mentioned embodiment 1, a region of the insulation film is arranged in the neighborhood of a boundary surface between it and a region of the second conducting film located at a side wall of the contact hole, constructed so that the inequality  $d_{\text{max}} \leq 0.1 t_{\text{max}}$  is satisfied, where  $t_{\text{max}}$  is the maximum film thickness of the insulation film and  $d_{\text{max}}$  is the maximum distance from the side wall of the contact hole to the insulation film.

(17) In the above-mentioned embodiment example 1, a region of the insulation film is provided in the neighborhood of a boundary surface between it and the second conducting film located at a side wall of the contact hole, constructed so that the inequality  $10 \text{ nm} \leq d_{\text{max}} \leq \text{nm}$  is satisfied, where  $d_{\text{max}}$  denotes the maximum distance from the side wall of the contact hole to the insulation film.

(18) In the above-mentioned embodiments 2-8, 9, and 10, the surface layer of the insulation film is constructed so that the inequality  $d_{\text{max}} \leq 0.1 t_{\text{max}}$  is satisfied, where  $t_{\text{max}}$  denotes the maximum film thickness of the insulation film and  $d_{\text{max}}$  the maximum distance from the surface of the insulation film to the surface layer of the insulation film.

(19) In the above-mentioned embodiments 2-8, 9, and 10, the surface layer of the insulation film is constructed so that the inequality  $10 \text{ nm} \leq d_{\text{max}} \leq 100 \text{ nm}$  is satisfied, where  $d_{\text{max}}$  denotes the maximum distance from the surface of the insulation film to the surface layer of the insulation film.

(20) As a system for producing a semiconductor device including a first conducting film, an insulation film provided with a contact hole, constructed so that the first conducting film is covered, and a second conducting film formed on the insulation film, that it is in electrical contact with the first conducting film through the contact hole, a system is used that is capable of performing continuously, without breaking the vacuum state, the step of forming a first insulation film with a viscosity of less than 10,000 cp to cover the first conducting film and the step of forming a second insulation film with a viscosity of not less than 10,000 cp.

(21) In the above-mentioned embodiment example 20, the above-mentioned step of continuously performance is performed, without breaking the vacuum state, in the same vacuum container.

(22) The viscosity-increasing treatment is performed before and/or after the step of forming a contact hole for electrically connecting the first conducting film and the second conducting film.

The viscosity-increasing treatment should preferably be performed before the step of forming a contact hole, in view of the formation of a resistance pattern with an excellent shape and forming a contact hole with an excellent shape. If the viscosity-increasing treating is performed after the formation of the contact hole, the viscosity-increasing treatment also has an effect on the side wall of the contact hole, so that the worsening of properties due its being subjected to subsequent deposition plasma can be prevented.

As explained above, in the semiconductor device according to the third embodiment example of the present invention, it is not the entire insulation film that has a low viscosity, rather, the portion of the insulation film onto which the upper second conducting film is formed has an increased viscosity, so that it is possible to obtain an insulation film that is excellent in comparison with the conventional insulation film in regard to the embedded shape in a groove and at the same time minimizes any bad effects on the next processes (e.g. in forming a contact hole or forming a conductor).

It is known that it is possible to form an insulation film with lower viscosity, which has a lower dielectric constant, and is less hygroscopic (corresponding to an insulation film with a viscosity of less than 10,000 cp according to the present invention) by using a deposition CVD process.

However, when a metallic film is used as a conductor, onto which an insulation film with such a low viscosity is formed by means of a deposition process such as magnetron deposition, the surface of the insulation film is damaged by the plasma used in the deposition.

As a result, some of the chemical bonds of a molecule composing the insulation film may be split or an irregular boundary surface can be formed between the insulation film and a conductor to be formed onto it (corresponding to the second conducting film of the present invention), whereby various problems can be caused, such as the generation of a leakage current between a pair of conductors arranged on both sides of the insulation film (corresponding to the first and the second conducting films of the present invention) or a disturbance to the insulation film.

If, however, a region of the insulation film, onto which the upper second conducting film has been condensed, has a high viscosity, as in the third embodiment example of the present invention, the damage to the surface of the insulation film by the plasma can be minimized, in which case it is possible to prevent effectively a disturbance to the insulation properties of the insulation film.

Also, if a through-hole is formed to connect the upper conductor with the lower conductor in an insulation film of lower viscosity, the position and the shape of the through-hole can become unstable because of deformation of the insulation film. If the viscosity of one part of the insulation film is increased, as recommended by the present invention, such a problem involving a through-hole can be avoided.

The present invention will be explained with reference to various characteristics shown in the drawings.

#### (Example 1)

Figure 1 is a schematic diagram of a semiconductor device used according to a first example of the present invention.

In Figure 1, reference number 1 denotes a vacuum container, to which an exhaust system (not shown) is connected through an outlet opening 2. This vacuum container 1 is evacuated to a vacuum of  $2 \times 10^{-7}$  torr or higher. A substrate-attachment table 3, made of stainless steel, is arranged inside the vacuum container 1, and a silicon substrate 4 is provided on this substrate-attachment table 3.

The vacuum container 1 is also connected to various tubes for the introduction of various gases into the vacuum container 1. One tube 5 of stainless steel, for the introduction of oxygen gas, one tube 15 of stainless steel for the introduction of tetramethylsilane ( $\text{Si}(\text{CH}_3)_4$ , denoted simply by TMS in the following), and one tube 30 of stainless steel, for the introduction of nitrogen gas, are connected to the vacuum container 1. Tube 5, for the introduction of oxygen gas (for simplicity, an oxygen supply system is omitted in Figure 1), is connected to a stop valve 6, a mass-flow control device 7, a stop valve 8, and a connector 9. The distal end region of the oxygen supply tube 5 is connected to an  $\text{Al}_2\text{O}_3$  tube 11.

This  $\text{Al}_2\text{O}_3$  tube 11 is connected to the vacuum container 1 through a connector 12 and is provided, in an intermediate region thereof, with a hollow space 10 for microwave discharge. The microwave source and the microwave supply system for the microwave discharge are omitted in Figure 1.

Tube 15, for the introduction of TMS (a TMS-supply system is omitted in Figure 1 for reasons of simplicity) is provided with a stop valve 16, a mass-flow control device 17, a stop valve 18 and a tube 19 of stainless steel, which is connected to the vacuum container 1.

The nitrogen gas supplied through tube 30 (the nitrogen gas supply device is omitted from Figure 1 for simplicity) is used to set the pressure in the vacuum container 1, i.e., to set the internal pressure of the vacuum container 1 to atmospheric pressure when the silicon substrate 4 is inserted into vacuum container 1, or removed, or to shorten the time required for restoring the

cooled temperature of the silicon substrate 4 to room temperature. This nitrogen gas can be used to set the internal pressure of the vacuum container 1 during deposition of a silicon dioxide film onto the silicon substrate 4.

Tube 30 is provided with a stop valve 31, a mass-flow control device 32, a stop valve 33, and a tube 34 of stainless steel, which is connected to the vacuum container 1.

The substrate-attachment table 3 is provided with copper tubes 35a and 35b for cooling or heating the substrate-attachment table 3 (copper tube 35a denotes a tube that is arranged on the gas-inlet side, while copper tube 35b denotes a tube that is arranged on the gas-outlet side), where these copper tubes 35a and 35b are concealed within the substrate-attachment table 3. These copper tubes 35a and 35b are connected to the nitrogen-supply system for the introduction of cooled nitrogen gas or nitrogen gas at room temperature, as shown in Figure 2.

With reference to the nitrogen supply system shown in Figure 2, reference number 101 denotes a tube for the introduction of nitrogen gas, which is connected to a nitrogen supply system (not shown). This tube 101 is provided with a stop valve 102, a mass-flow control device 103, and stop valves 104 and 105, and the distal end region of tube 101 is connected to tube 35a to cool or heat the substrate-attachment table 3, shown in Figure 1.

To this tube 101, a pair of branching tubes 106 and 109 are connected, which branch from the inlet side and the outlet side of stop valve 105. Branching tube 106 is connected to a stop valve 107 by a spiral tube 108, which is connected in turn to a stop valve 110 by a branching tube 109, which is connected to tube 35a, shown in Figure 1.

The spiral tube 108 is immersed in liquid nitrogen 112, which is filled into a container 111 for liquid nitrogen, in order for the nitrogen gas that flows through the spiral tube 108 to cool to a temperature that corresponds approximately to the temperature of the liquid nitrogen.

If the silicon substrate 4 is to be cooled, the nitrogen gas can flow through the spiral tube 108. On the other hand, if the temperature of a silicon substrate 4 that has been cooled in this manner is to be raised again to room temperature after formation of a silicon dioxide film, valve 105 is opened to introduce nitrogen gas at room temperature into tube 35.

By introducing nitrogen gas under control of the mass-flow control device and by cooling the liquid nitrogen gas, from tube 35a to tube 35b, the substrate-attachment device 3 and the silicon substrate 4 can be cooled down to a desired temperature.

Again with reference to Figure 1, the substrate-attachment table 3 is also provided with a housing heater 36, which functions as a heating source for heating the silicon substrate 4 to a desired temperature. The energy source for this housing heater 36 is omitted from Figure 1.

The wall of the vacuum container 1 is formed from a two-layer structure and provided with a heating source 41 to heat the wall and a heat-insulation material 42. The temperature of

the wall of vacuum container 1 is set in this example to 80°C. The energy source of the heating source 41 is omitted in Figure 1.

Next, a process for forming an intermediate-layer insulation film using the semiconductor fabrication system with the above-mentioned structure will be explained.

First, the inside of the vacuum container 1 is set to atmospheric pressure, and a silicon substrate 4 carrying the desired element is attached to a substrate-attachment table 3. In this case, an evacuated auxiliary chamber is provided, by means of which the silicon substrate 4 can be moved automatically to the vacuum container, in which process a robot arm is used. Then the inside of the vacuum container is set by means of the outlet opening 2 to a final vacuum, whereby a vacuum of at least  $1 \times 10^{-7}$  torr should be set in this case.

Then a cooled nitrogen gas can be introduced through a passage between copper tube 35a and copper tube 35b, by which means the substrate-attachment table 3 can be cooled to a particular temperature from about -100°C to -25°C. When the substrate-attachment table 3 has been cooled down to the above-mentioned temperature range, the temperature of the silicon substrate 4 (substrate temperature) is -80°C to -25°C. After it has been confirmed that the substrate temperature has been stabilized to the desired temperature, mass-flow control device 17 for TMS is set to 1-100 cm<sup>3</sup>/min and stop valves 16 and 18 are opened to introduce TMS into the vacuum container 1.

Mass-flow control device 10 for nitrogen gas is set to 1-1000 cm<sup>3</sup>/min and stop valves 6 and 8 are then opened to introduce oxygen gas into the vacuum container 1. In this case, the pressure in vacuum container 1 can be about 10 mtorr to about 500 torr by changing the conductance of the outlet opening 2, whereby the partial pressure is 2-200 torr for TMS and 2-400 torr for nitrogen gas.

After the nitrogen flow rate has stabilized, microwave radiation of about 100 W to 5 kW is applied, in order thereby to induce microwave discharge of the nitrogen gas. By defining the time when the microwave discharge is initiated as the start of the film deposition, the time of the film deposition is selected appropriately in order thereby for an intermediate-layer insulation film consisting of a compound including silicon, oxygen, carbon, and hydrogen to be deposited on the silicon substrate 4.

The above-mentioned deposition can be ended in the following manner.

First, the microwave power is turned off, in order to stop the microwave discharge. The time of this shutoff is defined as the end of the deposition time. Then stop valves 28 and 18 are closed to stop the supply of TMS, and after this stop valve 8 is closed to stop the supply of oxygen gas. Then the supply of cooling nitrogen gas flowing between tube 35a and tube 35b is stopped in the same way, and thereby nitrogen gas at room temperature can flow into the vacuum container 1.



In this case, the mass-flow control device 32 for nitrogen gas is set to 1-10 L/min and stop valves 31 and 32 [sic; 33] are opened to introduce nitrogen gas from tube 34 into the vacuum container 1 in order to set the inside of the vacuum container 1 to a pressure of approximately atmospheric pressure and at the same time to raise the temperature of the silicon substrate 4 back to room temperature.

Finally, the vacuum container 1 is set to atmospheric pressure and the silicon substrate 4 is removed from the vacuum container 1. If desired, the next silicon substrate can be attached to the substrate-attachment table 3 at this time. A series of processes of forming an intermediate-layer insulation film is completed in this way.

As explained above, an insulation-layer insulation film is formed according to this example that contains silicon, oxygen, carbon, and hydrogen, whereby the carbon content is greater than the silicon content. It has been established that when the carbon content is greater than the silicon content in a film containing silicon, oxygen, carbon, and hydrogen, the resulting insulation film becomes viscous at room temperature, in which case it is possible to improve the degree of coverage of the insulation film. It has likewise been established that a viscous insulation film of this type, consisting of a compound containing silicon, oxygen, carbon, and hydrogen, has a lower dielectric constant and is also less hygroscopic.

It is therefore possible, according to the invention, to obtain an intermediate-layer insulation film or an insulation-protection film that is excellent in regard to degree of coverage and both has a low dielectric constant and is less hygroscopic.

#### (Example 2)

Figures 3A and 3B show cross sections that explain the production of a semiconductor device according to a second example of the present invention.

Figure 3A shows a schematic cross section through a silicon substrate 201 before an intermediate-layer insulation film has been deposited thereon. After a silicon dioxide film 202 has been formed on the silicon substrate 201, which was previously provided with an insulated element region, the silicon dioxide film 202 is selectively etched away from a contact hole, and then a 1% Al, 0.5% Si Cu film (called simply an aluminum alloy film in the following) is deposited and etched, which functions as a connecting element 203, whereby a desired conductor pattern is formed, as shown in Figure 3A.

Next, the silicon substrate 201 is placed on the substrate-attachment table 3, which is provided in the vacuum container 1 of a semiconductor fabrication system of the same type as in the above-mentioned example 1, and the same procedure is repeated as shown in example 1 to

form an intermediate-layer insulation film 204 over the entire surface of the substrate 201, as shown in Figure 3B.

More specifically, the intermediate-layer insulation film 204 is formed under the following film-formation conditions: TMS-flow rate 20 cm<sup>3</sup>/min, oxygen-gas flow rate 200 cm<sup>3</sup>/min, deposition pressure 0.2 torr, microwave power 200 W, substrate temperature - 30°C, and deposition time 2 min. Under these film-formation conditions, the deposition rate of the intermediate-layer insulation film 204 is about 0.5 μm/min.

If the sample obtained under these conditions is observed by means of a scanning electron microscope (SEM), it is established that the intermediate-layer insulation film 204 has been deposited into the entire groove between the connection conductors 203 in the same manner as when a cup is filled with a liquid, i.e., no holes at all exist in the intermediate-layer insulation film 204 in the groove.

In another experiment performed by this inventor, an insulation film was formed on the flat surface of a silicon substrate, corresponding to the same procedure as above, and the resulting insulation film was analyzed by means of a transmission process using a Fourier-transform infrared spectrometer.

As a result, the absorption peaks that could be observed were a oscillation peak of Si - O - Si and an absorption peak of Si - CH<sub>3</sub>. The ratio of the Si - CH<sub>3</sub> to the Si - O - Si was 10-50 %.

Because of the imprecision of the detection sensitivity, it may be impossible to derive the concentration of each component directly from this data. If, however, the entire insulation film is dissolved by using a chemical wetting process, and the resulting solution is studied by means of an atom-absorption process, it is established that the composition ratio for carbon (C) to silicon (Si) is about 1:1 to 30:1, which in any case indicates a greater carbon content in comparison with silicon.

If the final vacuum in the vacuum container 1 is relatively low, an H<sub>2</sub>O peak appears in every experiment. The final vacuum of the vacuum container 1 should therefore preferably be as high as possible.

It can be said that the above-mentioned insulation film or intermediate-layer insulation film 204 is an insulation oil with high viscosity rather than an insulation film, since it has been established that the viscosity of the insulation film is 100-3000 cps. On the other hand, it has been established that the dielectric constant of the insulation film was about 1.8 to 3.2.

If the hygroscopic nature of the insulation film or the intermediate-layer insulation film 204 is studied by passing atmospheric air through it, water absorption hardly appears.

Moreover, if the insulation film or intermediate-layer insulation film 204 is heated to 650°C in vacuum and the gases released from it are measured using a mass spectrometer to study

the thermal stability of the film, a small amount of  $H_2O$  is detected at a temperature of  $300^\circ C$ , and in a temperature range of  $300-650^\circ C$ , only peaks are detected that contain C and H, i.e., no peak with  $H_2O$  is detected at all in this temperature range.

In another experiment, a silicon dioxide film with a thickness of  $0.5\ \mu m$  was formed on a silicon substrate, and then an aluminum-alloy film was formed onto it to a thickness of  $0.9\ \mu m$  by means of an ordinary magnetron vapor deposition process. Then a pattern consisting of the aluminum alloy was formed on the aluminum-alloy film by application of a conventional light-irradiation process and a reactive-ion deposition. Next, an insulation film with a thickness of  $2\ \mu m$  was deposited onto the entire surface of the silicon substrate, according to the process of this example, with sample A being obtained. On the other hand, a silicon dioxide film with a thickness of  $2\ \mu m$  was deposited over the entire surface of the silicon substrate, according to an ordinary plasma-CVD process, with sample B being obtained. If an electrical reliability test is performed with these samples, sample A shows a clearly higher reliability than sample B.

Since the intermediate-layer insulation film 204 formed according to this example was viscous, the film was rather soft in comparison with conventional silicon dioxide film. The main reason that insulation film 204 has an exceptionally high electrical reliability in comparison with conventional silicon dioxide films may be attributed to the fact that insulation film 204 is soft enough to be free of any kind of tensions that are usually found in conventional silicon dioxide films, so that any defects due to thermal tension could be avoided.

### (Example 3)

Figure 4 shows a schematic diagram of a semiconductor fabrication device that is used according to a third example of the present invention.

In Figure 4, reference number 301 denotes a vacuum container, to which an evacuation system (not shown) is connected through an outlet opening 302, in order to make it possible in this way for a high vacuum to exist inside the vacuum container 301. The final vacuum in this vacuum container 301 is  $2 \times 10^{-7}$  torr or higher. The evacuation system is not shown in Figure 4 in order to simplify the explanation.

A substrate-attachment table 303 to carry a substrate is placed inside the vacuum container 301, and a silicon substrate 304 is placed on this substrate-attachment table 303.

The vacuum container 301 is connected to various tubes to introduce various gases into the vacuum container 301. One tube 305, for introducing oxygen gas, one tube 315 for introducing an organic silane such as TMS, and one tube 330 for introducing nitrogen gas are connected to the vacuum container 301. Tube 305 is made of stainless steel.

Tube 305 for introducing oxygen gas (an oxygen supply system is omitted from Figure 4 for simplicity), is provided with a stop valve 306, a mass-flow control device 307, a stop valve 308, and a connector 309. The distal end region of the oxygen supply tube 305 is connected to an  $\text{Al}_2\text{O}_3$  tube 311.

This  $\text{Al}_2\text{O}_3$  tube 311 is connected to a stainless[-steel] tube 313 through a connector 312 that is connected to the vacuum container 301. The  $\text{Al}_2\text{O}_3$  tube 311 is provided in its middle region with a hollow space 310 for microwave discharge (for reasons of simplicity, a microwave source and a microwave-supply system are omitted in Figure 4).

The stainless[-steel] tube 313 is connected to a spray head 314, which is provided in the vacuum container 301 in such a way that it lies opposite the substrate-attachment table 303. The oxygen gas supplied by the stainless[-steel] tube 313 is fed to the substrate through the spray head 314 while it reacts with TMS. The spray head 314 can be heated or cooled to a desired temperature in the range from  $-70^\circ\text{C}$  to  $100^\circ\text{C}$  (for simplicity, the heating source and a control system for this heating and cooling are omitted in Figure 4).

Tube 315 for supplying TMS (for simplicity, a TMS-supply system is omitted from Figure 4) is provided with a stop valve 316, a mass-flow control device 317, a stop valve 318, and a tube 319 of stainless steel and connected to the vacuum container 301. A needle valve capable of controlling the flow rate can be used instead of the mass-flow control device 317.

Tube 319 of stainless steel is connected to the spray head 314 provided in the vacuum container 301. When oxygen gas and TMS are supplied simultaneously, these gases are mixed in the spray head 314 and partially react with each other, so that the mixture of these gases, which contains the reaction product, is fed to the substrate. It should be noted that the use of the spray head 314 is not essential according to the invention, i.e., the organic silane and the activated oxygen gas can be supplied separately to the vicinity of the surface of the substrate, in which case it is possible for these gases to be mixed in the vicinity of the surface of the substrate, whereby almost the same effect is achieved.

The nitrogen gas supplied by tube 330 (for simplicity, a nitrogen gas supply system is omitted from Figure 4) is used to set the pressure in the vacuum container 301, i.e., in order to set the internal pressure of the vacuum container 301 to atmospheric pressure, when the silicon substrate 304 is inserted into the vacuum container 301 or removed from it, or in order to shorten the time required for setting the cooled temperature of the silicon substrate 304 to room temperature. This nitrogen gas can be used to set the internal pressure of the vacuum container 301 during deposition of an insulation film on the silicon substrate 304.

Tube 330 is connected to a stop valve 331, a mass-flow control device 332, a stop valve 333, and a tube 334 connected to the vacuum container 301.

The substrate-attachment table 303 is [provided] with copper tubes (335a and 335b) for cooling or heating the substrate-attachment table 303 (copper tube 335a denotes a tube arranged on the gas-inlet side, while copper tube 335b denotes a tube arranged on the gas-outlet side), whereby these copper tubes (335a and 335b) are concealed within the substrate-attachment table 303. These copper tubes (335a and 335b) are connected to the nitrogen-supply system to introduce cooled nitrogen gas or nitrogen gas at room temperature.

The substrate-attachment table 303 is likewise provided with a housing heater 336, which functions as a heating source to heat the silicon substrate 304 to a desired temperature. The power source for this housing heater 336 has been omitted from Figure 4.

The wall of the vacuum container 301 is formed from a two-layer structure, and it is provided with a heating source 341 to heat the wall and a heat-insulation material 342 (the heating source 341 has been omitted in Figure 4). The wall temperature of the vacuum container 301 is set to 80°C in this example.

Next, a process for forming an insulation film, using the semiconductor fabrication system with the above-mentioned constitution, will be explained.

First, the vacuum container 301 is reset to atmospheric pressure and a silicon substrate 304 is attached to a substrate-attachment table 303. In this case, an evacuated auxiliary container can be provided next to the vacuum container 301 through a gate valve, in order to make it possible for the silicon substrate 304 to be moved automatically to the vacuum container 301, in which a robot arm is used. Then the inside of the vacuum container 301 is evacuated through the outlet opening 302 to a final vacuum, whereby in this case a vacuum of at least  $1 \times 10^{-7}$  torr should be set.

Then, cooled nitrogen gas can flow from copper tube 335a to copper tube 335b, in which case the substrate-attachment table 303 is cooled to a predetermined temperature from about -100 to -25°C. When the substrate-attachment table 303 has been cooled down to the above-mentioned range, the temperature of the silicon substrate 304 (substrate temperature) is -80°C to -25°C. When it has been confirmed that the substrate temperature has been stabilized to the desired temperature, mass-flow control device 317 for TMS is set at 1 to 100 cm<sup>3</sup>/min and stop valves 316 and 318 are opened to introduce TMS into the vacuum container 301.

After this, mass-flow control device 310 for oxygen gas is set to 1 to 1000 cm<sup>3</sup>/min and stop valves 306 and 308 are opened to introduce oxygen gas into the vacuum container 301. In this case, the pressure in the vacuum container 301 is set to approximately 10 mtorr to 500 torr, by which the conductance of the outlet opening 302 is changed, whereby the partial pressure is 2-200 torr for TMS and 2-400 torr for oxygen gas.

After the flow rate of oxygen has stabilized, microwave radiation of about 100 W to 5 kW is applied, in order thereby to induce microwave discharge of oxygen gas. By defining

the time when the microwave discharge is initiated as the starting time of the film deposition, the film deposition time is selected appropriately, in order thereby to deposit a silicon dioxide film on the silicon substrate 304.

In this example, an activated oxygen gas is fed directly into the vacuum container 301. Since the flow rate of oxygen gas and the resonance of the microwave do not stabilize immediately, it is advisable, from the standpoint of obtaining a insulation film with excellent quality, to introduce the oxygen gas directly into the vacuum container 301, but through a bypass, after the flow rate of oxygen gas and resonance of the microwave have stabilized.

The above-mentioned deposition can be ended by means of the following procedure.

First, the microwave power is turned off to stop the microwave discharge. The time of this shutoff is defined as the end time of the deposition. Then stop valves 328 and 318 are closed to stop the supply of TMS, and after this the stop valve 308 is closed to stop the supply of oxygen gas. Then the supply of cooling nitrogen gas from tube 335a and tube 335b is stopped in the same way as described above. At this time, the mass-flow control device 332 for nitrogen gas is set to 1-10 L/min and stop valves 331 and 332 are opened to introduce nitrogen gas from tube 334 into the vacuum container 301, in order thereby to reset the vacuum container 301 to a pressure in the vicinity of atmospheric pressure, and at the same time the temperature of the silicon substrate 304 is raised back to room temperature.

Finally, the vacuum container 301 is set to atmospheric pressure and the silicon substrate 304 is removed from the vacuum container 301. If desired, the next silicon substrate is attached to the substrate-attachment table 303 at this time. A series of processes for forming a silicon oxide film is completed in this way.

An intermediate-layer insulation film was formed on a substrate carrying a connecting conductor (sample), whereby work was done according to the above-mentioned procedures, as shown in Figures 5A and 5C.

This sample was produced as follows. First, a thermal silicon dioxide film 402 was deposited on the silicon substrate 401, which carries an element (not shown), to a thickness of about 1  $\mu\text{m}$ , and then a 1-% Al, 0.5-% Si film (called simply aluminum-alloy film in the following), which functions as an aluminum-alloy conductor 403 and is connected to the above-mentioned element, is deposited to a thickness of about 0.4 to 0.9  $\mu\text{m}$ . Then the resulting aluminum-alloy film is ion-etched by use of a usual exposure process and reactive-ion etching (RIE), whereby a desired aluminum-alloy conductor is formed, as shown in Figure 5A. This aluminum-alloy conductor 403 was connected to the above-mentioned element through a contact hole formed in the thermal silicon dioxide film 402.

Next, the silicon substrate 401 is placed on the substrate-attachment table 303, which is provided in the vacuum container 301, and the same procedure explained above is repeated to form an insulation film 405, as shown in Figure 5B.

More specifically, the intermediate-layer insulation film 204 is formed under the following film-formation conditions:

TMS-flow rate  $20 \text{ cm}^3/[\text{min}]$ , oxygen-gas flow rate  $200 \text{ cm}^3/\text{min}$ , deposition pressure 0.2 torr, microwave power 200 W, substrate temperature  $-30^\circ\text{C}$ , and deposition time 2 min. With these film-formation conditions, the deposition rate of the intermediate-layer insulation film 405 is about  $0.1$  to  $0.5 \text{ }\mu\text{m}/\text{min}$ . When the sample obtained under these conditions is observed with a scanning electron microscope (SEM), it was established that the insulation film 405, as shown in Figure 5B, had been deposited uniformly into the entire intermediate space 404 between the conductors 403, as when a cup is filled with water, i.e., no holes at all exist in the insulation film 405 that has deposited into the groove.

Then an  $\text{SiO}_2$  film 406 is deposited over the insulation film 405 up to a thickness of about  $0.5$  to  $1 \text{ }\mu\text{m}$  by means of a plasma-CVD system of the parallel-plate type, using tetraethoxysilane (TEOS) and oxygen (Figure 5C). After a contact hole (through-hole) as been formed for contact with the aluminum-alloy conductor 403 in the  $\text{SiO}_2$  film 406, a second layer of an aluminum-alloy conductor is formed. The procedure is then repeated the desired number of times to form the desired multi-layer conductor. Since the insulation film 405 is viscous, the insulation film 405 formed on the aluminum-alloy conductor is preferably set as thinly as possible, so that the next steps can be performed appropriately.

The main characteristic of this example lies in the difference in film thickness between film thickness "a" of the isolation film 405 that was deposited on the aluminum-alloy conductor 403 and film thickness "b" of the isolation film 405 that was deposited into the groove 404, as shown in Figure 5B. Film thickness "b" of the insulation film 405 that had been deposited into the groove 404 was greater than film thickness "a" of the insulation film 405 that had been deposited onto the aluminum-alloy conductor 403.

Figure 6 explains the relationship between film thickness "a" and film thickness "b." As shown in Figure 6, film thickness "b" is clearly greater than film thickness "a," until the groove 404 is completely filled with the insulation film 405.

Therefore, when the deposition of the insulation film 405 is stopped at the point indicated by the symbol "x" in Figure 6, it is possible to obtain structure in which the groove 405 [sic; 404] is completely filled with the insulation film 405, but whereby the surface of the aluminum-alloy conductor 403 is barely covered with the insulation film 405.

Figure 5B shows an example in which the insulation film 405 is likewise deposited onto the upper surface of the aluminum-alloy conductor 403, although the deposited insulation

film 405 is thin. However, the insulation film 405 need not necessarily be deposited onto the aluminum-alloy conductor 403, but only onto the thermal silicon dioxide film between the conductors.

Since the insulation film 405 in this example has a relatively low dielectric constant in comparison to the usual silicon dioxide film, even when the insulation film 405 is provided only in the space between the conductors, this is effective for preventing inter-conductor capacitance in the lateral direction.

Since the insulation film 405 in this example is viscous, it is soft in comparison to the usual silicon dioxide film. The softness of this insulation film 405 is a great advantage from a certain point of view, but it can also become disadvantageous, as will be explained below. The basis for the improvement in electrical reliability of the insulation film 405 can be attributed to the fact that the insulation film 405 is soft enough to be free of any type of thermal tensions that are found in the conventional silicon dioxide film, so that any defects based on thermal tension can be avoided.

On the other hand, the softness of the insulation film (204) can interfere with a subsequent step. If, e.g., the insulation film 405 is deposited on an entire aluminum-alloy layer that constitutes a first layer, onto which the insulation film 405 is deposited by the usual magnetron vapor deposition process, the insulation film 405 becomes wrinkled because of the heat of deposition, whereby it becomes impossible to form the aluminum-alloy conducting layer uniformly onto it and consequently to continue with the next steps.

However, according to this example, the soft insulation film 405 existed mainly in a region between the aluminum-alloy conductors, and the upper surface of the aluminum-alloy conductor was in contact with the  $\text{SiO}_2$  film 406, which was formed by the usual plasma-CVD process. Naturally, the soft insulation film 405 must have existed on the aluminum-alloy conductor, but it was impossible to detect the existence of the soft insulation film 405 on the aluminum-alloy conductor when it was observed with a scanning electron microscope (SEM). Since the surface of the insulation film 405 was covered with a  $\text{SiO}_2$  film formed by means of a usual plasma-CVD method, the next steps could be performed without interference from the existence of the insulation film 405.

Although a combination of TMS and oxygen has been explained in this example, nearly the same effect can be achieved by using other kinds of organic silanes instead of TMS. Examples of such organic silanes are alkoxysilanes such as tetraethyl silane ( $\text{Si}(\text{C}_2\text{H}_5)_4$ ), tetramethoxysilane ( $\text{Si}(\text{OCH}_3)_4$ ), tetraethoxysilane ( $\text{Si}(\text{OC}_2\text{H}_5)_4$ ), hexamethyldisiloxane ( $\text{Si}_2\text{O}(\text{CH}_3)_6$ ), and tetraisopropoxysilane ( $\text{Si}(\text{i-C}_3\text{H}_7)_4$ ). It is likewise possible to use xylene, phenyltrimethylsilane, and diphenyltrimethylsilane, in which case almost the same effects are obtained.



It is likewise possible to use a compound that includes an oxygen atom as a component instead of  $O_2$ . Examples of such compounds include ozone, CO,  $CO_2$ , NO,  $N_2O$ ,  $NO_2$ ,  $H_2O$ , and  $H_2O_2$ , in which case nearly the same effects are obtained.

(Example 4)

Figures 7A through 7C each show a cross section, whereby a step in the production of a semiconductor fabrication device according to a fourth example of the present invention is explained.

As shown in Figure 7A, a thermal silicon dioxide film 502 with a thickness of  $1\text{ }\mu\text{m}$  is formed on the silicon substrate 501, and then an aluminum-alloy film is deposited that functions as an aluminum-alloy conductor 503, with a thickness of  $0.9\text{ }\mu\text{m}$ , by means of the usual deposition process. Next a pattern is formed on the resulting aluminum-alloy film by use of the usual irradiation process and a reactive-ion etching, whereby a desired pattern is formed from an aluminum-alloy conductor 503.

In Figure 7A, reference number 504 denotes a groove between the conductors. The aluminum-alloy conductor 503 is connected through a contact hole (not shown) formed in the thermal silicon dioxide film 502 to an element (not shown) formed on the silicon substrate 501.

Next, the silicon substrate 501 is treated in the same way as in the third example, with formation of an insulation film 505, as shown in Figure 7B. The film-formation conditions used in this case are: TMS flow rate  $20\text{ cm}^3/\text{min}$ , oxygen gas flow rate  $100\text{ cm}^3/\text{min}$ , deposition pressure 0.2 torr, microwave power 500 W, substrate temperature: room temperature. These film-formation conditions are only an example, and hence the present invention should not be limited thereto.

When these conditions are set in such a way that oxygen radicals are easily generated, a conformal film, as shown in Figure 7B, can be obtained easily. Conditions that make it possible to generate oxygen radicals easily are: when the oxygen flow rate is relatively greater than the TMS flow rate; when the microwave power is relatively high; or when the temperature of the substrate is as close as possible to room temperature.

When the sample formed under these conditions was observed with a scanning electron microscope (SEM), it was established that the thickness of the insulation film 505 that was formed at the bottom of the groove 504 was nearly the same as the thickness formed on the conductor 503, as shown in Figure 7B.

The main characteristic of this example is not only in the fact that the film thickness of the insulation film 505 formed at the bottom of the groove 504 was nearly the same as the thickness of the insulation film 505 formed on the aluminum-alloy conductor 503, but also in the

fact that a certain amount of the insulation film 505 (film thickness 0.1 to 0.5  $\mu\text{m}$ ) is also formed on the aluminum-alloy conductor 503. When the inter-conductor capacitance in the lateral direction is to be lowered, the gap between the conductors should be covered with the insulation film 505 as much as possible.

After the substrate 501 is removed from the vacuum container, an  $\text{SiO}_2$  film 506 is deposited onto the entire insulation film 505 up to a thickness of about 0.5 to 1.0  $\mu\text{m}$  by the usual plasma-CVD process. It can be effective for improving the embedded shape of the groove 504 to deposit an insulation film 0.2 to 0.6  $\mu\text{m}$  thick in advance, using an organic silane and  $\text{O}_2$ , and then an  $\text{SiO}_2$  film 506 onto the insulation film by a plasma-CVD process.

Then, an upper aluminum-alloy conductor is formed by the usual process. After the formation of a contact hole to form a contact with the aluminum-alloy conductor 503 in the  $\text{SiO}_2$  film 506, an aluminum-alloy film with a thickness of 0.4 to 1.0  $\mu\text{m}$  is formed to form the upper aluminum-alloy conductor. A pattern is then formed from the aluminum-alloy film using both a usual irradiation process and also a reactive-ion etching process, whereby the upper aluminum-alloy conductor is formed.

After an  $\text{SiO}_2$  film with a thickness of 0.5 to 1.0  $\mu\text{m}$  has been formed by a plasma-CVD process, a connecting surface is formed.

The semiconductor device (sample) obtained in this way was tested to study the electrical reliability. As a result, it was established that the percentage affected by defects because of tension migration was reduced by a two-digit value in comparison with the conventional semiconductor device.

This result can be attributed to the fact that since the insulation film 505 that contacts the aluminum-alloy conductor 503 is a viscous insulation film, even when the  $\text{SiO}_2$  film 506 formed by a plasma-CVD process on the insulation film 505 is provided with the usual thermal tension, any type of thermal tension that can be applied to the aluminum-alloy conductor 503 can be alleviated through the viscous insulation film 505.

This example is characterized by the fact that the insulation 505 with a thickness of about 0.1 to 0.5  $\mu\text{m}$  is also formed on the upper surface of the aluminum-alloy conductor 503. The upper surface as well as the side walls of the aluminum-alloy conductor 503 were completely surrounded by the soft insulation film 505.

It is suspected that when the semiconductor device is constructed in this way, it is possible to reduce any thermal tensions in the  $\text{SiO}_2$  film 506 formed on the insulation film 505 by a plasma-CVD process, whereby the generation of tension migration is suppressed.

The fact that the intermediate-layer insulation film is not completely formed by the insulation film 505 is likewise one of the characteristics of the present invention. The generation not only of tension migration, but also of electron migration when the voltage is increased, is

likewise one of the factors that cause a worsening of the electrical reliability of the aluminum-alloy conductor.

As a countermeasure to suppress the generation of tension migration, a process is used with generation of a blocking layer consisting of TiN on the upper and lower sides of the aluminum-alloy conductor. Corresponding to this structure, when a large voltage is applied to the aluminum-alloy conductor, the aluminum atoms move in the direction in which the voltage is applied. The aluminum atoms that have moved toward the downstream side become excess atoms for the aluminum-alloy conductor of the downstream side. Since the upper and lower surfaces of the aluminum-alloy conductor are covered by a hard TiN blocking layer, the aluminum atoms that have moved in this way along a weak region of the insulation film in the vicinity of both sides of the aluminum-alloy conductor accumulate (a side hillock). If this side hillock becomes large as a result of its growth, it can come into contact with the neighboring aluminum-alloy conductors, whereby a short-circuit is caused.

If the gap provided between the aluminum-alloy conductors is filled completely with the soft insulation film 505, the resistance against these side hillocks becomes low. However, it has been confirmed that when the soft insulation film 505 is deposited only on a limited region that contacts the aluminum-alloy conductors, and the rest of the space between the aluminum-alloy conductors is filled with the conventional  $\text{SiO}_2$  film 506, as in this example, the resistance to this side hillock is not affected.

#### (Example 5)

Figure 8 shows a cross section that explains a semiconductor device according to a fifth example of the present invention.

In Figure 8, reference number 701 denotes a silicon substrate that carries an insulated element. A silicon dioxide film 702 is formed on the upper surface of the silicon substrate 701. Onto this silicon dioxide film 702, a desired pattern of conductors, i.e., conductors 703a, 703b, and 703c is deposited. These conductors (703a, 703b, and 703c) are formed electrically with elements (not shown) that are formed on the upper surface of the substrate and are connected electrically through contact holes (not shown) formed in the silicon dioxide film 702.

These conductors (703a, 703b, and 703c) were covered by an insulation film 704 formed according to the present invention. A conducting layer 705 was formed on the insulation film 704 and connected to conductor 703b through a through-hole 706 formed in the insulation film 704. The material that constitutes these conductors (703a, 703b, and 703c) can be, e.g., a 1-%Al, 0.5-%Si, Cu conductor.

Figure 9 shows a schematic diagram of a semiconductor fabrication device used in this example. The semiconductor fabrication device is suitable for forming the insulation film 704 by a deposition CVD process.

With reference to Figure 9, reference number 601 denotes a vacuum container, to which an evacuation system (not shown) is connected through an outlet opening 602, in order to make it possible for the inside of the vacuum container 601 to be set to a high vacuum. The final vacuum of this vacuum container 601 is  $2 \times 10^{-7}$  torr or higher. The evacuation system is not shown in Figure 9 in order to simplify the explanation.

A substrate-attachment table 603 to carry a substrate is placed inside the vacuum container 601, and a silicon substrate 604 is provided on the substrate-attachment table 603.

The vacuum container 601 is connected to various tubes for the introduction of various gases into the vacuum container 601. In this case, one tube 605 for the introduction of various types of process gases, such as oxygen gas, hydrogen gas, carbon monoxide gas, or nitrogen gas, and a cleaning gas; one tube 615 for the introduction of an organic silane, such as TMS; and one tube 630 for the introduction of nitrogen gas are connected to the vacuum container 601. Tube 605 is made, e.g., of stainless steel.

Tube 605 for the introduction of various types of process gases (for simplicity, a gas-supply source is omitted from Figure 9) is connected through valves 606a through 606i to mass-flow control devices (607a through 607i), as shown from top to bottom in Figure 9. The distal end region of the oxygen supply tube 605 is connected to an  $\text{Al}_2\text{O}_3$  tube 611.

Tube 605 is provided with a valve 608 and with a connector 609 and a sapphire tube 611, which is connected to the vacuum container 601 through a connector 612. Tube 605 is also connected through valves 651 and 652 to an ozonizer 653. When ozone is to be used, valve 608 is closed and a starting material is supplied to the ozonizer through valve 652. The ozone-containing gas is fed back through valve 652 to valve 605. As the starting-material gas to be fed to the ozonizer 653, oxygen gas, a mixed gas including oxygen gas and nitrogen gas, or a mixed gas including oxygen gas and carbon-dioxide gas is used preferably.

The sapphire tube 611 is preferably provided in its middle region with a discharge electrode 610 to generate a plasma by microwave discharge (for simplicity, a microwave source and microwave supply system are omitted in Figure 9). A light source 654 to excite a gas fed through the tube can be attached near the sapphire tube 611. As the exciting light that is to be used in this case, ultraviolet radiation is preferred to induce the gas supplied that is to be excited into an electron state [sic].

Tube 615 for the introduction of TMS (for simplicity, a TMS-supply source is omitted in Figure 9) is connected to the vacuum container 601 through a stop valve 616, a massflow control

device 617, a stop valve 618, and a tube 619 of stainless steel. A needle valve that can control the flow rate precisely can be used instead of the mass-flow control device 617.

The nitrogen gas to be fed through tube 630 (for simplicity, a nitrogen-gas supply source is omitted in Figure 9), is used to set the pressure within the vacuum container 601, i.e., to reset the internal pressure of the vacuum container 601 to atmospheric pressure, when the substrate 604 is placed in the vacuum container 601, or removed from it, or to shorten the time required for restoring the cooled temperature of the silicon substrate 604 to room temperature. This nitrogen gas can be used to set the internal pressure of the vacuum container 601 during deposition of an insulation film on the substrate 604. Tube 630 is connected to the vacuum container 601 through a valve 631, a mass-flow control device 632, valve 633, and a tube 634.

The substrate-attachment table 603 is provided with copper tubes (635a and 635b) for cooling the substrate-attachment table 603 (copper tube 635a denotes a tube that is arranged on the gas-inlet side, while copper tube 635b denotes a tube arranged on the gas-outlet side), whereby these copper tubes (635a and 635b) are concealed within the substrate-attachment table 603. These copper tubes (635a and 635b) are connected to a nitrogen supply system for the introduction of cooled nitrogen gas or nitrogen gas at room temperature (for simplicity, the nitrogen-gas cooling system and nitrogen-gas supply system are not shown in Figure 9).

The substrate-attachment table 603 is also provided with a housing-heater 636 that functions as a heating source to heat the silicon substrate 604 to a desired temperature (the power source for this housing heater 634 is not shown in Figure 9).

The wall of the vacuum container 601 is formed from a two-layer structure and equipped with a heating source 641 and a heat-insulation material 642 for heating the wall of the vacuum container 601, in order to maintain in this way a uniform gas temperature distribution in the internal space of the vacuum container 601 (for simplicity, the power source for this heating source 641 is not shown in Figure 9).

A light source 655, which is used to increase the viscosity of the region in the vicinity of the surface of the insulation film, and a microwave-generation power source 656 are attached to the vacuum container 601. As a light source 655, any infrared source with a wavelength of 2.6-3.3  $\mu\text{m}$ , ultraviolet source 142 with a wavelength of 308 nm, or a light source for rapidly increasing the temperature of a substrate can be used effectively. This light source 656 and microwave-generation power source 655 can be used singly or in any combination, including multiply.

Next, a process for forming an insulation film corresponding to the present invention will be explained with reference to Figures 9 and 10A through 10C, whereby the process is modeled on the actual procedure.

First, the inside of the vacuum container 601 was reset to atmospheric pressure, and a substrate 604 was attached to a substrate-attachment table 603. In this case, an evacuated auxiliary chamber next to the vacuum container 601 can be provided via a gate valve in order to make it possible for the silicon substrate 604 to be transferred automatically to the vacuum container 601, in which a robot arm is used. The substrate 604 used in this case was a silicon substrate, the upper surface of which had been provided with a silicon dioxide film 702, onto which conductors 703a, 703b, and 703c had also been formed in a desired pattern, as shown in Figure 10A.

Then, the vacuum container 601 was set through the evacuation opening 602 to a final vacuum, which should be vacuum of  $1 \times 10^{-7}$  torr or higher in this case. Then cooled nitrogen gas could flow through a passage between copper tube 635a and copper tube 635b, whereby the substrate-attachment table 603 was cooled to a certain temperature from about  $-100^{\circ}\text{C}$  to  $-25^{\circ}\text{C}$ . When the substrate-attachment table 603 had been cooled down to the above-mentioned range, the temperature of the silicon substrate 604 (substrate temperature was  $-80^{\circ}\text{C}$  to  $-25^{\circ}\text{C}$ . After it was confirmed that the substrate temperature had stabilized to the desired temperature, mass-flow control device 617 for TMS was set to 1 to  $100 \text{ cm}^3/\text{min}$  and stop valves 616 and 618 were opened to introduce TMS into the vacuum container 601.

Mass-flow control device 607g for oxygen gas was then set to 1 to  $1000 \text{ cm}^3/\text{min}$  and stop valves 606g and 608 were opened to introduce oxygen gas into the vacuum container 601. In this case, the pressure in the vacuum container 601 can be set from about 10 mtorr to 500 torr by changing the conductance of the evacuation opening 602, whereby the partial pressure is 2-200 torr for TMS and 2-400 torr for oxygen gas.

After the flow rate of the oxygen gas had stabilized, microwave power of about 100 W to 5 kW was applied, in order thereby to induce microwave discharge of oxygen gas. As a result, an insulation film 704 consisting of a reaction product between the oxygen plasma and TMS was deposited on the silicon substrate 701 in such a way that the conductors (703a through 703c) were covered, as shown in Figure 10B.

The above-mentioned deposition was ended by the following procedure.

First, the microwave source power was turned off in order to stop the microwave discharge. Then, stop valves 616 and 618 were closed to stop the introduction of TMS, and then valves 606g and 608 were closed to stop the introduction of oxygen gas. Then the introduction of cooled nitrogen gas, which was flowing from tube 635a to tube 635b, was stopped, and nitrogen gas at room temperature could flow through instead.

In this case, the mass-flow control device 632 for nitrogen gas was set to 1 to  $10 \text{ L}/\text{min}$ , and valves 631 and 632 were opened to introduce nitrogen gas from tube 634 into the vacuum container 601, in order to reset the inside of the vacuum container 601 to a pressure in the

vicinity of atmospheric pressure, and at the same time the temperature of the silicon substrate 604 was raised back to room temperature.

Finally, the inside of the vacuum container 601 was set to atmospheric pressure and the silicon substrate 604 was removed from the vacuum container 601. If desired, the next silicon substrate can be attached to the substrate attachment table 603 at this time. A series of processes for forming an intermediate-layer insulation film was completed in this manner.

Typical processes conditions for the formation of the above-mentioned insulation film 704 are: TMS flow rate  $20 \text{ cm}^3/\text{min}$ , oxygen-gas flow rate  $200 \text{ cm}^3/\text{min}$ , deposition pressure 0.2 torr, microwave power 200 W, and substrate temperature  $-30^\circ\text{C}$ . Under these film-formation conditions, the deposition rate of the insulation film 704 is about  $0.5 \text{ }\mu\text{m}/\text{min}$ .

In this example, the discharge time was set to 40 min, and the film thickness of the insulation film 704 obtained was  $2 \text{ }\mu\text{m}$ . The viscosity of this insulation film 704 was less than 10,000 cp and the insulation film 704 was so soft that it could be perforated easily with tweezers [sic].

As shown in Figure 10C, a through-hole 706 was then opened in the insulation film 704 in such a way that it was connected to conductor 703b. Then the following procedures were performed in order, e.g., to raise the viscosity selectively in a region near the surface of the insulation film 704.

The substrate 701 was again placed in the vacuum container 601, which is shown in Figure 9. Then the flow rate of oxygen was set to  $150 \text{ cm}^3/\text{min}$  through mass-flow control device 607f. Valve 606f was then opened, high-frequency power of 200 W was applied to the discharge electrode 610, a hydrogen-gas plasma was introduced through the sapphire tube 611 into the vacuum container 601, and the substrate 701 was heated with a heater 636 to a temperature of  $300^\circ\text{C}$ . In this way, the substrate 701 was kept in this hydrogen-gas atmosphere for, e.g., 10 min. The internal pressure of the vacuum container 601 was, e.g., 1 torr.

Then, nitrogen gas was introduced into copper tube 635a to copper tube 635b, and at the same time, nitrogen gas from tube 634 was introduced into the vacuum container 601 in the same manner as explained above. When the temperature of the substrate had reached approximately room temperature, the substrate 701 was removed from the vacuum container 601.

The insulation film 704, the surface layer of which was then subjected to the above-mentioned treatment to increase its viscosity, became so hard that it could no longer be perforated easily with tweezers, which indicates a viscosity of 10,000 cp or more.

Finally, conductor 703b, which had been provided at the bottom of the through-hole 706, was cleaned by means of a suitable washing treatment, and then a metal conductor, from which conductor 705 was to be formed, was deposited on the insulation film 704 by a magnetron-deposition process. Then, the metallic layer was processed by use of an irradiation

process and a reactive-ion etching process to form conductor 705, which was connected electrically to conductor 703b, producing the semiconductor device shown in Figure 8.

The region of the semiconductor device obtained according to this example, and likewise the region of the semiconductor device formed according to the conventional procedure, i.e., the surface layer of its insulation film not subjected to the above-mentioned viscosity-increasing treatment, was studied using a scanning electron microscope (SEM).

As a result, it was established that the cross section of the insulation film 704 of the semiconductor device according to this example was excellent in every respect, including the upper surface and the side wall of the through-hole 706. Moreover, a sharp boundary surface indicating a change in viscosity was observed at an internal region of the insulation film 704, located about  $0.1\ \mu\text{m}$  inside the surface of the insulation film 704 and about  $0.05\ \mu\text{m}$  inside the side wall of the through-hole 706. The groove between the conductors, as well as the raised region of the conductors, was completely covered with the insulation film 704, without any kind of holes been generated in it.

In contrast to this, fine irregularities on the upper surface of the insulation film 704 and on the side wall of the through-hole 706 of the semiconductor device produced according to the conventional procedure were found due to the fact that the above-mentioned viscosity-increasing treatment had not been performed on the insulation film 704 and at the side wall of the through-hole 706, although the groove between the conductors and the raised region of the conductors was completely covered with the insulation film 704. Since the viscosity of the insulation film 704 itself was low, it was determined that the shape of the through-hole 706 was also deformed.

When a test relating to electrical properties was performed with the semiconductor device of the present invention and with the conventional semiconductor device, it was determined that the lifetime of the conductors of the semiconductor device of the present invention was about 10% longer than that of the conventional semiconductor device.

The reasons for this difference in the lifetime of the conductors will be explained in the following. The reasons for the shortened lifetime of the conductors of the conventional semiconductor device can be attributed to the deterioration of various properties caused by the plasma used in the deposition process, such as the magnetron-deposition process; e.g., a deterioration attributable to the generation of a leakage current resulting from the irregularity of the surface of the insulation film 704 or from splitting of bonds in the molecular structure of which the insulation film 704 is made, or a deterioration that can be attributed to defects that interfere with the contacts of the conductors. In contrast, it is assumed in this example that these phenomena are suppressed by the viscosity-increasing treatment performed on the surface of the insulation film 704. It is expected that the improvement in the reliability of the conductors



through the structural improvement of an insulation film, as described above, will become increasingly clear when miniaturization of the semiconductor element progresses further.

For a comparison of the quality of the insulation film obtained according to the present invention with the quality of the conventional insulation film, these insulation films were formed on a flat surface of a silicon substrate.

As a sample for the conventional insulation film, an insulation film was formed with the conventional deposition-CVD process (viscosity less than 10,000 cp). On the other hand, as a sample for the insulation film corresponding to this example, an insulation film was formed with the conventional deposition-CVD process and then the above-mentioned viscosity-increasing treatment was performed on the insulation film for a long time in order to raise the viscosity of most of the insulation film (viscosity more than 10,000 cp).

Then this insulation film was studied by a permeation Fourier-transform infrared analysis, an atom-composition analysis consisting of a combination of a wet chemical process and an atom-absorption analysis or mass-spectroscopy, and a hygroscopicity test. As a result, it was established that these insulation films have the same quality as far as the precision that can be determined by these analyses is concerned.

The main peaks that could be observed in the infrared spectroscopy analysis were an Si-O-Si path-vibration peak and a Si-CH<sub>3</sub> path-vibration peak. The intensity ratio of the Si-CH<sub>3</sub> vibration peak to the Si-O-Si peak was 10 to 50% in all insulation films. If the final vacuum in the vacuum container 201 was low, the H<sub>2</sub>O absorption peak could not be observed in any of these insulation films, which indicates that the final vacuum in the vacuum container 201 should be set as high as possible.

When all insulation films that had been deposited onto the silicon substrate were dissolved by means of a wet chemical process and the resulting solutions were studied by atom-absorption analysis and mass spectrometry, it was determined that the composition ratio between carbon (C) and silicon (Si) was between 1.1:1 to 20:1 in all these insulation films, which indicates a higher carbon content compared to silicon in all of these insulation films.

In view of the evaluation of the hygroscopicity of these insulation films, even when these insulation films were exposed to an air atmosphere for two days, practically no water absorption could be detected in any of these insulation films. When these insulation films were heated in vacuum to up to 650°C and the gases released from them were measured using a mass spectrometer in order to study the thermal stability of these insulation films, a small amount of H<sub>2</sub>O was detected at a temperature of 300°C, and in the temperature range from 300 to 650°C, the only peaks detected contained C and H, i.e., no H<sub>2</sub>O peak was detected at all in this temperature range.

From these results, it can be seen that even when the above-mentioned viscosity-increasing treatment for the upper surface layer of an insulation film is performed on the insulation film that has been deposited by a deposition-CVD process, the quality of the insulation film is not essentially changed as a whole.

Therefore, the excellent qualities that are inherent in an insulation film formed by the conventional CVD process, i.e., a low dielectric constant and low hygroscopicity of the insulation film are not adversely affected, even when the viscosity of the surface layer of the film is increased. In contrast to this, it can be said that when the above-mentioned viscosity-increasing treatment is performed on the insulation film, the bonds between the molecules in the surface layer of the film are strengthened so that the dielectric constant and hygroscopicity of the insulation film can be lowered even further.

The fact that only the surface layer of the insulation film has a high viscosity and the interior region of the insulation film is kept at a low viscosity is highly preferred as a characteristic for an insulation film between conducting layers (i.e., an intermediate-layer insulation film). This is because when the viscosity of the surface layer of the insulation film is high, the location and also the shape of a through-hole formed selectively in the insulation film are stabilized. In addition, any damage to an insulation film by deposition plasma during the formation of a metallic conducting layer by means of magnetron deposition after the formation of the insulation film is effectively avoided when the viscosity of the surface layer of the insulation film is high. Therefore, the generation of a loss voltage between a pair of conductors through the insulation film can be effectively prevented.

On the other hand, if the viscosity of the interior region of the insulation film is low, there is no possibility for tension to be transferred to the insulation film lying below it, and at the same time, the step-covering property and the surface flatness of the insulation film are improved. In this case, it is also possible to prevent the conductor from damage due to tension migration.

As explained above, the above-mentioned viscosity-increasing treatment to increase the viscosity only at the surface layer of the insulation film formed by a deposition-CVD-process is a very effective process for obtaining an insulation film that has a low dielectric constant, is not very hygroscopic, and has an excellent step-covering property and is minimally affected by plasma and the like.

This example can be modified in various ways, as explained below.

For example, the above-mentioned viscosity-raising treatment to increase the viscosity only at the surface of the insulation film 704 can be performed directly before the substrate 701 is removed from the vacuum container 201 after deposition of the insulation film 704 by a deposition-CVD process. If this viscosity-increasing treatment is performed in this way, any kind of change in the location and the shape of the through-hole 706 because of some kind of

deformation of the insulation film 704 during the formation of the through-hole 706 in the insulation film 704 is effectively prevented.

In addition, these viscosity-increasing treatments to raise the viscosity only of the surface layer of the insulation film 704 after it has been condensed by a deposition-CVD process should preferably be performed in sequence, without breaking the vacuum state. The reason for this is that when the insulation film 704 is directly exposed to an air atmosphere after it has been condensed, the surface of the insulation film 704, which still has a low viscosity, can absorb fine particles that may have a negative effect on the quality of the insulation film 704 and on the conductors 706 to be formed on the insulation film 704.

In addition, these viscosity-increasing treatments to increase the viscosity of only the surface of the insulation film 704 after it has been condensed by a deposition-CVD process are preferably performed in the same vacuum container in order to avoid deformation of the insulation film 704 during transportation and any absorption of dust in the interior of the system.

According to this example, TMS reacts with oxygen radicals in a vapor phase and the reaction product is deposited onto a substrate, resulting in formation of an insulation film (a deposition-CVD). It is assumed that this reaction product is a polymerization-reaction product, and it derives from an organic silane and oxygen radicals. It is therefore possible to use other kinds of organic silane instead of TMS. Examples of such organic silanes are tetraethylsilane, tetramethoxysilane, tetraethoxysilane, hexamethyldisiloxane, and tetraisopropoxysilane. As sources of oxygen radicals that can react with the organic silane, it is possible to use an oxygen-containing gas instead of  $O_2$ . Examples of such gases include ozone, CO,  $CO_2$ , NO,  $N_2O$ ,  $NO_2$ ,  $H_2O$ , and  $H_2O_2$ .

In order to increase the viscosity of the surface of the insulation film 704 formed by means of a deposition-CVD process, an oxygen-radical atmosphere was used in this example.

It is suspected that this increase in viscosity by the reaction of active components in a polymer product that derives from organic silane and oxygen-rich radicals (e.g.  $(Si(R_1R_2)-O)_n$ , where  $R_1$  and  $R_2$  are each side chains), which constitute the insulation film 704 like the Si-end and the O-end of a side chain, i.e., a polymerization or linking reaction is induced among the molecules that form the insulation film through these active regions, whereby the structure of the insulation film is strengthened.

This strengthening of the insulation film by a linking reaction of this kind also contributes to an improvement in the lowering of the dielectric constant and the hygroscopicity of the insulation film, which are required for insulation films from the technological viewpoint in the production of semiconductor devices.

In view of the above-mentioned mechanism, it is possible to use other kinds of starting materials instead of the oxygen radicals in the above-mentioned viscosity-raising treatment, in order to raise the viscosity of the surface layer of the insulation film 704 selectively.

As a means for introducing a linking reaction, it is possible to increase the viscosity of the surface layer of the insulation film 704 formed by a deposition-CVD process by using method that is capable of introducing an active nucleus that contains an oxygen atom to the surface layer of the insulation film 704. For example, a plasma of a gas atmosphere that includes a molecule that contains oxygen atoms or ozone can be used.

Examples of a molecule that contains oxygen atoms and can be used in this case are those that are composed of the same kinds of atoms as are present in the insulation film 704 (such as CO and CO<sub>2</sub>) or those that contain atoms that exist in the insulation film 704 and atoms that can be dissociated from the insulation film 704 (NO, N<sub>2</sub>O, NO<sub>2</sub>, H<sub>2</sub>O, and H<sub>2</sub>O<sub>2</sub>).

It is also possible to use hydrogen radicals to increase the viscosity of the surface layer of the insulation film 704. It is suspected that the increase in viscosity in this case is caused by removal of the R<sub>1</sub>-Si and R<sub>2</sub>-Si bonds from the Si-O network of the molecule (e.g. (Si(R<sub>1</sub>R<sub>2</sub>)-O)<sub>n</sub>, where R<sub>1</sub> and R<sub>2</sub> are each side chains), which constitute the insulation film 704, by converting these bonds into R<sub>1</sub>-H and R<sub>2</sub>-H, respectively, where a reaction in the Si-O network is induced whereby the chemical bonds in the insulation film are strengthened.

It is also possible to increase the viscosity of the surface layer of the insulation film 704 by promoting the reaction of specific functional groups in the insulation film 704 by inducing a vibration excitation of the functional groups. This can preferably be accomplished by using an excitation light for the OH bond, which is present in small amounts in the insulation film 704, and it is assumed that this is a reason for the low viscosity of the film. The light that was effective in increasing the viscosity of the film was an infrared light with a wavelength of about 2.6 to 3.3 μm, which corresponds to the absorption wavelength of the OH bond. This infrared light was effective in exciting the OH bonds, which existed primarily in the side chains, R<sub>1</sub> and R<sub>2</sub>. The use of an infrared light with a wavelength of 3.3 to 3.5 μm was likewise effective in increasing the viscosity of the insulation film 704.

It is also possible to increase the viscosity of the surface layer of the insulation film 704 by irradiating ultraviolet light onto the insulation film 704 in order to excite the electron state of the molecules that constitute the insulation film 704. In particular, the use of ultraviolet radiation with a wavelength of 142 to 308 nm is most effective. In this case, an excimer lamp [sic; laser] is used as the light source. However, any other kind of light source could also be used.

It is also possible to increase the viscosity of the surface layer of the insulation film 704 by heating only the surface layer of the insulation film 704. If, e.g., a substrate that carries the insulation film 704 with low viscosity is exposed to microwaves, the water molecules that are

present to a small extent in the surface layer of the insulation film are excited, whereby only the surface of the insulation film 704 is heated and the linking reaction between the molecules that constitute the insulation film 704 is promoted.

The atmosphere used in this case should preferably be one that does not interfere with the linking reaction, such as an inert gas atmosphere (such as a nitrogen or argon gas atmosphere) or an atmosphere with reduced pressure. Alternatively, an argon gas atmosphere including oxygen atoms can be used to generate most of the active nuclei that contain the oxygen atoms that are to be generated by microwaves to promote the linking reaction.

It is also possible to use a "high-nucleus" temperature-control system provided with, e.g., an infrared heat lamp. In this case, when the rate of temperature increase is too low, not only the surface but also the interior of the insulation film 704 is heated, whereby a linking reaction is caused in the interior of the insulation film 704. Linking in the interior of the insulation film 704 is undesirable, since any tension in the insulation film 704 can be transmitted to the underlying conductors (703a to 703c).

In regard to the specific heat capacity and heat conductance rate of the insulation film 704 and the temperature dependency of the linking reaction, a heating rate of 10°C/min or more is required. The final temperature should preferably be about 450°C to 700°C. When the substrate has been heated to this final temperature, the temperature should preferably be directly at 450°C or slightly lower and maintained at this temperature, in order to avoid any deformation of the conductors (703a through 703c).

The process conditions such as treatment temperature, gas pressure, gas flow rate, discharge power, light intensity, wavelength of the light, treatment time, or rate of increase or decrease in the temperature in the above-mentioned treatments to raise the viscosity of the surface layer of the insulation film 704 can be modified, depending on various factors such as the starting material and the viscosity of the insulation film 704, the depth of the layer with increased viscosity, and the desired viscosity of the insulation film 704. It is also possible to combine a number of treatment processes.

Although Figure 9 shows an example of various processes to deposit an insulation film and to increase the viscosity of the surface layer of the insulation film, a system that uses only a part of the design shown in Figure 9 can be used as required. For example, the region of the design that is adapted for use in increasing the viscosity of the surface layer of the insulation film is separated from the region that is adapted for use in the deposition step of the insulation film, and a system that comprises one of these regions can be used as required.

In this example, a silicon substrate is used, but other kinds of substrates, such as a GaAs substrate, a ZnSe substrate, or an SOI substrate could likewise be used instead of the silicon substrate.

Although the step of selective formation of a contact hole in the insulation film 704 using a separate system has been performed, the sequence of steps, including the step of depositing the insulation film, the step of increasing the viscosity of the surface layer of the insulation film, and the step of forming a contact hole can be performed continuously, without a break in the vacuum state, in a suitable system. This sequence of steps can be performed in the same vacuum container.

If a process to increase the viscosity of the surface of the insulation film 704 with low viscosity and also the viscosity of the side-wall region of a through-hole by inducing a linking reaction at the surface of the insulation film and also at the side-wall region of the through-hole is used, then a deeper region of the insulation film 704 is also very viscous, which causes any tensions in the insulation film 704 to be transferred to the underlying conductors (703 and 703c).

If it is desired to prevent the transfer of tensions from the insulation film 704 to the underlying conductors (703a and 703c), the maximum film thickness,  $t_{\max}$ , of the insulation film 704 should preferably be set so that the inequality  $d_{\max} \leq 0.1 t_{\max}$  is satisfied, where  $d_{\max}$  denotes the maximum distance from the surface of the insulation film 704 or from the side wall of the through-hole 706 to the region of high viscosity of the insulation film 704.

This maximum distance, " $d_{\max}$ ", from the surface of the insulation film 704 or from the side wall of the through-hole 706 to the region of high viscosity of the insulation film 704 should be, in regard to the minimum value required to prevent deformation of the insulation film 704 and any damage by the plasma and in regard to the value at which the effects for preventing the above-mentioned deformation and damage are sufficient, about  $10 \text{ nm} \leq d_{\max} \leq 100 \text{ nm}$ .

As a means of creating a surface layer with a lower viscosity on the insulation film (a first insulation film), a separate insulation film (a second insulation film) with a high viscosity can be formed instead of increasing the viscosity of the surface layer of the insulation film 704.

In this case, the film thickness of the second insulation film is not limited by the above-mentioned " $d_{\max}$ ", but can be changed as required, depending on the quality of the second insulation film and the layout of the semiconductor device.

The second insulation film should preferably be formed after the formation of the first insulation film and before the formation of the through-hole. The second insulation film can be formed after the step of forming the through-hole, but in this case the second insulation film will possibly also be formed at the bottom of the through-hole. If the film thickness of the second insulation film that is formed at the bottom surface of the through-hole is large, a step of reopening the through-hole may be required.

The step of forming the second insulation film with a higher viscosity than the viscosity of the first insulation film can be performed by using a CVD process, as is used in this example, under process conditions that make it possible to increase the viscosity of the insulation film.

Specifically, the flow rate of oxygen gas is made smaller with respect to the flow rate of an organic silane gas or the discharge power for generating oxygen radicals is increased, whereby the degree of polymerization of the polymerization reaction product between the organic silane and oxygen gas radicals is increased.

The process of forming the second insulation film can also be performed by using the tetraethoxysilane (TEOS)-ozone process or the polymerization process of an organic material to form a polymer film.

The step of forming the second insulation film after the formation of the first insulation film should preferably be performed continuously, without breaking the vacuum state. If a substrate that carries the first insulation film is exposed to an air atmosphere directly after it has been deposited, the surface of the first insulation film, which still has a low viscosity, is susceptible to adsorbing fine particles and water, which may possibly be disadvantageous for the quality of the insulation film and for the conductors formed onto the first insulation film.

In addition, the step of forming the second insulation film should preferably be performed after the formation of the first insulation film in the same vacuum container in order to prevent deformation of the insulation film while it is being transferred and any adsorption of dust to the interior of the system.

A treatment to raise the viscosity of the surface layer of the first insulation film (insulation film 704) can be performed after the formation of the first insulation film and before the step of forming the second insulation film.

In this example, a CVD process can be used to form an insulation film. However, the present invention can also be used for another process for forming an insulation film with low viscosity. Properties such as low dielectric constant, low hygroscopicity, and low viscosity, which are required for the insulation film, are based on requirements such as high-speed response, thermal tension, and step coverage, which are required for a circuit.

In particular, as a countermeasure for the problems of step coverage, thermal tension, and surface flatness, an insulation film with low viscosity must be formed on the upper surface of the substrate. One goal of the present invention is that of improving the resistance of the insulation film to damage and to improve the processing precision of the insulation film while maintaining the low dielectric constant, low hygroscopicity, and low viscosity (interior region) of the film, which are required for an insulation film, whereby the above-mentioned goal is achieved by forming an insulation film that has low viscosity, except for its surface layer, which has high viscosity.

The present invention is not limited to the above-mentioned examples. For example, the present invention was explained with reference to an intermediate-layer insulation film in the

above-mentioned examples. However, the present invention is also usable for a protective insulation film (passivation film).

If a large surface of the passivation film 805 of the present invention is arranged in the vicinity of the periphery of a bonding/connecting surface or in the vicinity of the peripheral circuit, as shown in Figures 11A and 11B, the blind connection column 806 should first be formed with formation of the conductor 803 through formation of the pattern from an aluminum-alloy film. The passivation film 805 can be formed in the same way as the intermediate-layer insulation film 204.

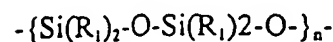
The blind connection column 806 can be formed using a film formed from an insulating material that is different from the above-mentioned silicon dioxide film 804, such as a plasma-CVD silicon dioxide film or a silicon nitride film. If a film of these materials is used, the problem that the passivation film 805 may deform because of pressure applied to conductor 803 during a bonding step can be avoided. In Figures 11A and 11B, reference number 801 denotes a silicon substrate, and reference number 807 a contact hole (through-hole).

Almost the same effect can be obtained by thermal hardening of the surface of the passivation film 805 at a low temperature of 300°C or less instead of forming the blind connection column 806.

As explained above, according to the present invention, it is possible to create an insulation film that can be embedded within a fine region, while its excellent shape is maintained.

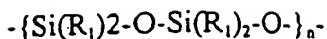
### Claims

1. Semiconductor device, characterized by a substrate 201 and at least one intermediate-layer insulation film 204 or one passivation-insulation film, each of which is formed on the substrate 201 and contains silicon, oxygen, carbon, and hydrogen, where the carbon content is greater than the silicon content.
2. Semiconductor device according to Claim 1, where the insulation film has a dielectric constant of 1.8 to 3.2.
3. Semiconductor device according to Claim 2, where the insulation film has a dielectric constant of 1.8 to 2.5.
4. Semiconductor device according to one of Claims 1 through 3, wherein the insulation film has a backbone chain with structure selected from the group consisting of the following formulas 1 through 5:



where  $R_1$  is  $C_nH_{2n+1}$  (where  $n$  denotes a positive integer);





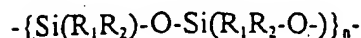
2

where  $R_1$  is  $-O-C_nH_{2n+1}$  (where  $n$  denotes a positive integer);



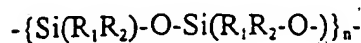
3

where  $R_1$  is  $C_nH_{2n+1}$  (where  $n$  denotes a positive integer) and  $R_2$  is  $C_mH_{2m+1}$  (where  $m$  denotes a positive integer), where  $n$  differs from  $m$ ;



4

where  $R_1$  is  $-O-C_nH_{2n+1}$  (where  $n$  denotes a positive integer) and  $R_2$  is  $-O-C_mH_{2m+1}$  (where  $m$  denotes a positive integer), where  $n$  differs from  $m$ ; and



5

where  $R_1$  is  $-O-C_nH_{2n+1}$  or  $C_nH_{2n+1}$  (where  $n$  is a positive integer);  $R_2$  is  $-O-C_mH_{2m+1}$  or  $C_mH_{2m+1}$  (where  $m$  is a positive integer), where  $n$  differs from  $m$  and where at least one of  $R_1$  and  $R_2$  is connected by  $-O-$  with  $R_1$  or  $R_2$  belonging to the other backbone chain.

5. Semiconductor device according to one of Claims 1 through 4, wherein a connection column consisting of a metallic material or an insulation material that is resistant with respect to deformation of the insulation layer is embedded in the insulation film.

5. [sic; 6] Semiconductor device according to one of Claims 1 through 5, wherein a surface layer of the insulation film has a higher viscosity than the rest of the insulation film.

7. Semiconductor device according to one of Claims 1 through 6, whereby the insulation film is inert and not capable of releasing water at a temperature below  $650^\circ\text{C}$ ,

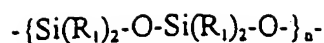
8. Semiconductor device according to one of Claims 1 through 7, wherein the atomic ratio of carbon to silicon in the insulation film is 1.0 to 3.0.

9. Semiconductor device, characterized by a substrate 201 and at least either an intermediate-layer insulation film 204 or a passivation-insulation film, each formed on a substrate 201, including silicon, oxygen, carbon, and hydrogen, and viscous at room temperature, whereby it has a viscosity of 100 cps to 300,000 cps at room temperature.

10. Semiconductor device according to Claim 9, wherein the insulation film has a dielectric constant from 1.8 to 3.2.

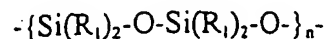
11. Semiconductor device according to Claim 10, wherein the insulation film has a dielectric constant from 1.8 to 2.5.

12. Semiconductor device according to one of Claims 9 and 11, wherein the insulation film has a backbone chain with a structure selected from the group consisting of the following formulas 1 through 5:



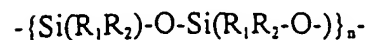
1

where  $R_1$  is  $C_nH_{2n+1}$  (where  $n$  denotes a positive integer);



2

where  $R_1$  is  $-O-C_nH_{2n+1}$  (where  $n$  denotes a positive integer);



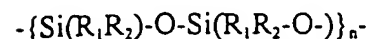
3

where  $R_1$  is  $C_nH_{2n+1}$  (where  $n$  denotes a positive integer) and  $R_2$  is  $C_mH_{2m+1}$  (where  $m$  denotes a positive integer), where  $n$  differs from  $m$ ;



4

where  $R_1$  is  $-O-C_nH_{2n+1}$  (where  $n$  denotes a positive integer) and  $R_2$  is  $-O-C_mH_{2m+1}$  (where  $m$  denotes a positive integer), where  $n$  differs from  $m$ ; and



5

where  $R_1$  is  $-O-C_nH_{2n+1}$  or  $C_nH_{2n+1}$  (where  $n$  is a positive integer);  $R_2$  is  $-O-C_mH_{2m+1}$  or  $C_mH_{2m+1}$  (where  $m$  is a positive integer), where  $n$  differs from  $m$  and where at least one of  $R_1$  and  $R_2$  is connected by  $-O-$  to  $R_1$  or  $R_2$  belonging to the other backbone chain.

13. Semiconductor device according to one of the Claims 9 through 12, wherein a connection column consisting of a metallic material or an insulation material that is resistant with respect to deformation of the insulation film is embedded in the insulation film.

14. Semiconductor device according to one of Claims 9 through 13, wherein a surface layer of the insulation film has a higher viscosity than the rest of the insulation film.

15. Semiconductor device according to one of Claims 9 through 14, wherein the insulation film is inert and not capable of releasing water at a temperature below 650°C.

16. Semiconductor device according to one of Claims 9 through 15, wherein the atomic ratio of carbon to silicon is 1.0 to 3.0.

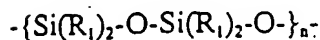
17. Semiconductor device, comprising a semiconductor substrate that carries an element, a first insulation film formed on the semiconductor substrate, a number of conductors, whereby at least one of the conductors is electrically connected via a contact hole; a second insulation film formed onto the conductors and onto the first insulation film where conductors have not been formed and containing silicon, oxygen, carbon, and hydrogen, whereby the carbon content is not less than the silicon content; and

a third insulation film formed onto the second insulation film and made of a material that differs from the material from which the second insulation film is made.

18. Semiconductor device according to Claim 17, wherein the insulation film has a dielectric constant of 1.8 to 3.2.

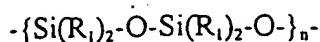
19. Semiconductor device according to Claim 18, wherein the insulation film has a dielectric constant of 1.8 to 2.5.

20. Semiconductor device according to one of Claims 17 through 19, wherein the insulation film has a backbone chain with a structure selected from the group consisting of the following formulas 1 through 5:



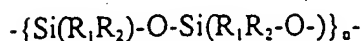
where  $R_1$  is  $C_nH_{2n+1}$  (where  $n$  denotes a positive integer);

1



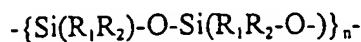
where  $R_1$  is  $-O-C_nH_{2n+1}$  (where  $n$  denotes a positive integer);

2



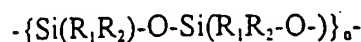
where  $R_1$  is  $C_nH_{2n+1}$  (where  $n$  denotes a positive integer) and  $R_2$  is  $C_mH_{2m+1}$  (where  $m$  denotes a positive integer), where  $n$  differs from  $m$ ;

3



where  $R_1$  is  $-O-C_nH_{2n+1}$  (where  $n$  denotes a positive integer) and  $R_2$  is  $-O-C_mH_{2m+1}$  (where  $m$  denotes a positive integer), where  $n$  differs from  $m$ ; and

4



where  $R_1$  is  $-O-C_nH_{2n+1}$  or  $C_nH_{2n+1}$  (where  $n$  is a positive integer);  $R_2$  is  $-O-C_mH_{2m+1}$  or  $C_mH_{2m+1}$  (where  $m$  is a positive integer), where  $n$  differs from  $m$  and where at least one of  $R_1$  and  $R_2$  is connected by  $-O-$  to  $R_1$  or  $R_2$  belonging to the other backbone chain.

5

21. Semiconductor device according to one of Claims 17 through 20, wherein a connection column consisting of a metallic material or an insulation material that is resistance with respect to deformation of the insulation film is embedded in the insulation film.

22. Semiconductor device according to one of Claims 17 through 21, wherein a surface layer of the insulation film has a higher viscosity than the rest of the insulation film.

23. Semiconductor device according to one of Claims 17 through 22, wherein the insulation film is inert and not capable of releasing water at a temperature below 650°C.

24. Semiconductor device according to one of Claims 17 through 23, wherein the atomic ratio of carbon to silicon is 1.0 to 3.0.

25. Semiconductor device according to one of Claims 17 through 24, wherein the second insulation film is viscous at room temperature, where it has a viscosity from 100 to 300,000 cps at room temperature.

26. Semiconductor device according to one of Claims 17 through 25, wherein a film thickness of the third insulation film formed on an upper surface of the second insulation film is thinner than the film thickness of the third insulation film, which is formed on the upper surface of the first insulation film, between the conductors.

27. Semiconductor device according to one of Claims 17 through 26, wherein the first insulation film and the second insulation film are formed from a silicon dioxide film.

28. Semiconductor device, characterized by a semiconductor substrate;  
a first conducting film formed on the semiconductor substrate;  
an insulation film that is provided with a contact hole and formed in such a way that the first conducting film is covered; and

a second conducting film formed onto the insulation film in such a way that it is in electrical contact with the first conducting film through the contact hole;

wherein a region of the insulation film is arranged in the vicinity of a boundary surface between it and the second conducting film, without a region being provided at the contact hole, constituted in such a way that it has a viscosity of 10,000 cp or more and the rest of the insulation film, without the region in the vicinity of the boundary surface between it and the second conducting film, constructed in such a way that it has a viscosity of not less than 10,000 cp.

29. Semiconductor device according to Claim 28, wherein a region of the insulation film is arranged in the vicinity of a boundary surface between it and a region of the second conducting film located at the side wall of the contact hole, constructed so that it has a viscosity of 10,000 cp or more.

30. Semiconductor device according to Claim 28 or 29, wherein a region of the insulation film is arranged in the vicinity of a boundary surface between it and the second conducting film located at a side wall of the contact hole, constituted so that the inequality  $d_{\max} \leq 0.1 t_{\max}$  is satisfied, where  $t_{\max}$  denotes a maximum film thickness and  $d_{\max}$  denotes a maximum distance from the boundary surface with the second conducting film to the region of the insulation film arranged in the vicinity of the intermediate surface.

31. Semiconductor device according to Claim 28, wherein a region of the insulation film is arranged in the vicinity of a boundary surface between it and a region of the second conducting film located at a side wall of the contact hole, constituted in such a way that the following inequality is satisfied:  $10 \text{ nm} \leq d_{\max} \leq 100 \text{ nm}$ , where  $d_{\max}$  denotes the maximum distance from the boundary surface between it and the second conducting film to the region of the insulation film arranged in the vicinity of the boundary surface.

32. Process for producing a semiconductor device, including the following steps:  
forming a first insulation film on a semiconductor substrate that carries an element;  
forming a contact hole in the first insulation film;  
forming a number of conductors on the first insulation film, wherein at least one of the many conductors is in electrical contact with the element through the contact hole;

forming a second insulation film on the first insulation film where the conductors have not been formed, in such a way that the space between the conductors is covered, and wherein the second insulation film contains silicon, oxygen, carbon, and hydrogen, whereby the carbon content is not less than the silicon content;

and

forming a third insulation film on the conductors and on the second insulation film, wherein the third insulation film is made of a material that differs from the material of which the second insulation film is made.

33. Process according to Claim 32, wherein the step for forming the second insulation film is performed by a CVD process, wherein an organic silane and oxygen in an excited state are used as starting materials and a substrate temperature of  $-70^{\circ}\text{C}$  to  $50^{\circ}\text{C}$  is set.

34. Process for producing a semiconductor device, including the following steps:

forming a conducting film on a substrate;

forming an insulation film with a viscosity of less than 10,000 cp in order thereby to cover the first conducting film;

performing a viscosity-increasing treatment by means of which the viscosity of a surface layer of the insulation film is increased to not less than 10,000 cp; and

forming a second conducting film on the insulation film in such a way that it is in electrical contact with the first conducting film.

35. Process according to Claim 34, wherein the step of increasing the viscosity of a surface layer of the insulation film to not less than 10,000 cp is performed by treating the insulation film with a plasma of a gas that includes at least one molecule that contains oxygen.

36. Process according to Claim 34, wherein the step of increasing the viscosity of a surface layer of the insulating film to not less than 10,000 cp is performed by treating the insulation film with a gas that contains oxygen radicals, ozone, or hydrogen radicals.

37. Process according to Claim 34, wherein the step of increasing the viscosity of the surface layer of the insulation film to not less than 10,000 cp is performed by irradiating the insulation film with an infrared radiation source with a wavelength of 2.6 to  $3.3\text{ }\mu\text{m}$ .

38. Process according to Claim 34, wherein the step of increasing the viscosity of a surface layer of an insulation film to not less than 10,000 cp is performed by irradiating the insulation film with an ultraviolet radiation source with a wavelength from 142 to 308 nm.

39. Process according to Claim 34, wherein the step of increasing the viscosity of a surface layer of the insulation film to not less than 10,000 cp is performed by treating the insulation film with microwaves in an atmosphere of a gas that includes at least one molecule containing an oxygen atom, an atmosphere of an inert gas, or an atmosphere with reduced pressure.

40. Process according to Claim 34, wherein the step of increasing the viscosity of the surface layer of the insulation film to not less than 10,000 cp is performed by heating the substrate that carries the insulation film at a heating rate of 10°C/s and by maintaining the heating temperature at 450°C or less.

41. Process according to Claim 34, wherein the step of increasing the viscosity of a surface layer of the insulation film to not less than 10,000 cp is performed by heating the substrate that carries the insulation at a heating rate of 10°C/s, wherein the surface layer of the insulation film is heated to a temperature in the range from 450°C to 700°C.

42. Process for fabricating a semiconductor device, including the following steps:  
forming a first conducting film onto a substrate;  
forming an insulation film with a viscosity of less than 10,000 cp, in order thereby to cover the first conducting film;  
forming a second insulation film with a viscosity of not less than 10,000 cp onto the first insulation film; and  
forming a second conducting film onto the second insulation film, in such a way that it is in electrical contact with the first conducting film.

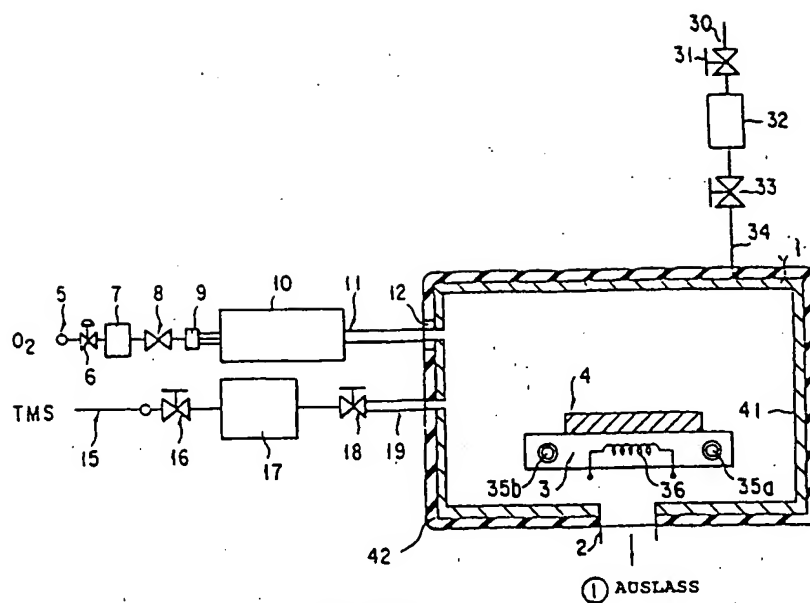


FIGURE 1

Key: 1 Exhaust

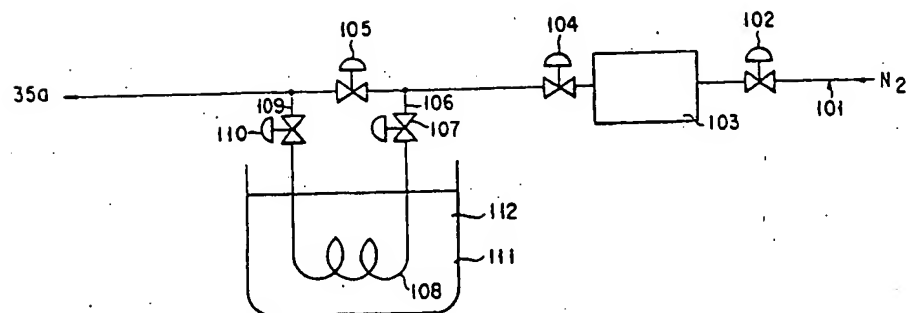


FIGURE 2

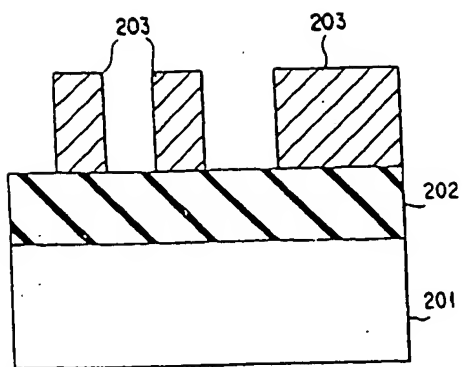


FIGURE 3A

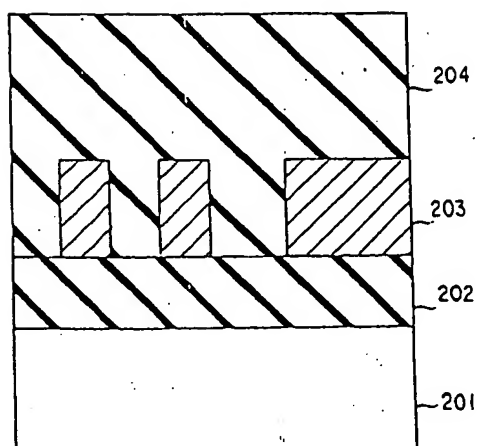


FIGURE 3B \*

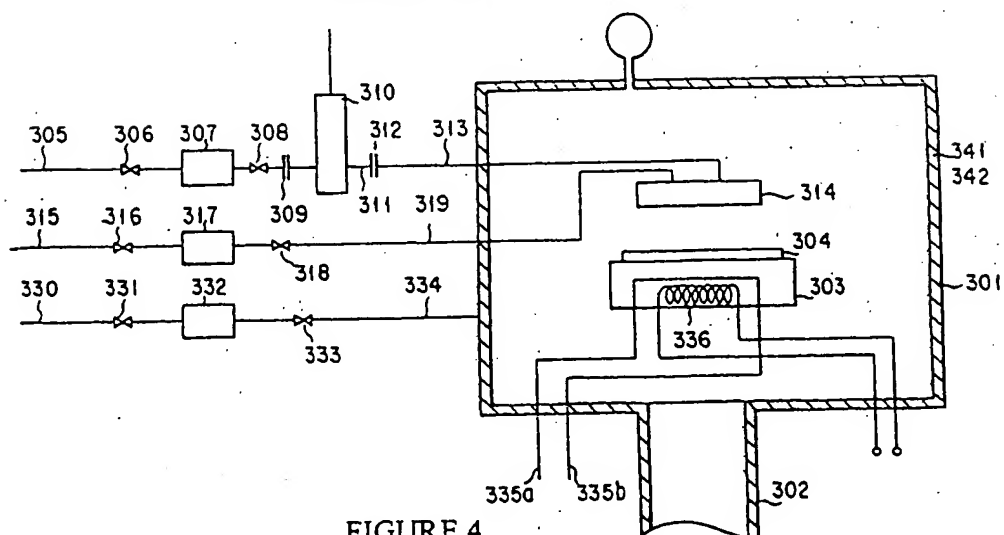


FIGURE 4



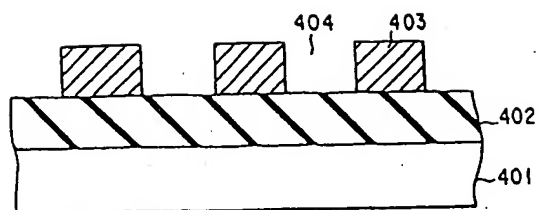


FIGURE 5A

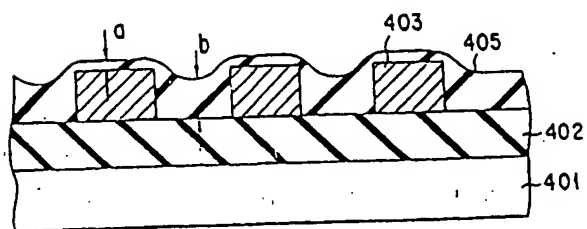


FIGURE 5B

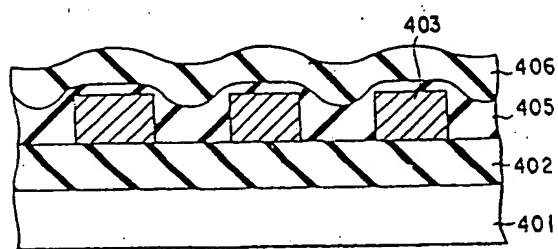


FIGURE 5C

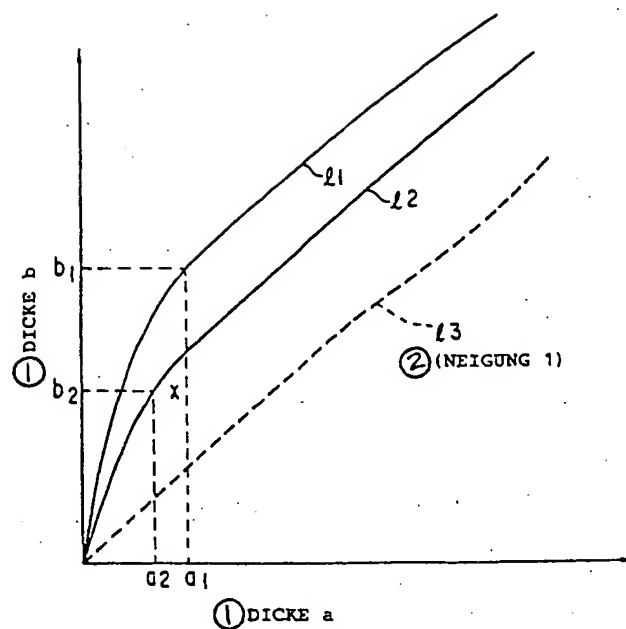


FIGURE 6

Key: 1 Thickness  
2 Bending

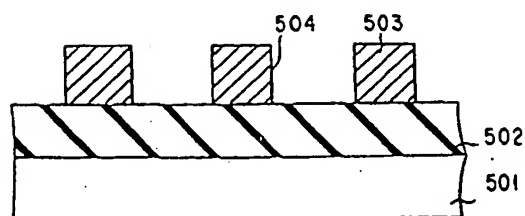


FIGURE 7A

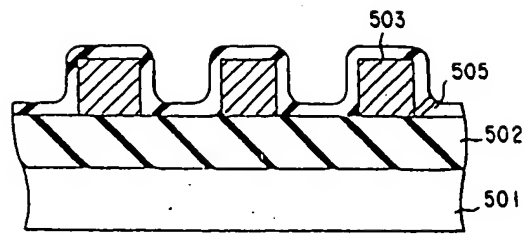


FIGURE 7B

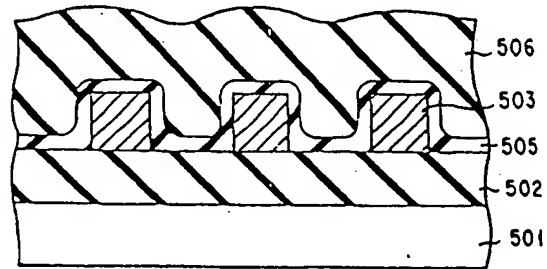


FIGURE 7C

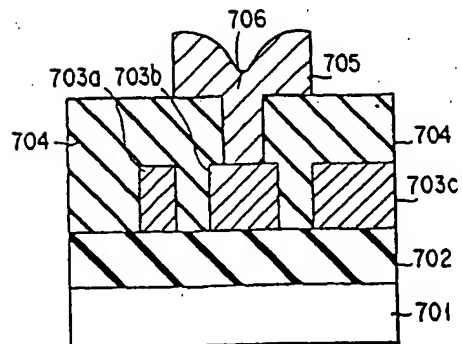


FIGURE 8



German Patent Application No. 196 54 737 A1

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